ORIGINAL ARTICLES

AGRICULTURAL METEOROLOGY

STUDIES ON SOIL-MOISTURE IN RELATION TO MOISTURE IN THE SURFACE LAYERS OF THE ATMOSPHERE DURING THE CLEAR SEASON AT POONA

BY

L. A. RAMDAS, M.A., Ph.D.,

Agricultural Meteorologist, Meteorological Office, Poona

AND

M. S. KATTI, B.Sc.,

Research Student

(Received for publication on 25th May 1936)

(With Plate LXVI and ten text-figures)

INTRODUCTION

In a previous communication* [Ramdas and Katti, 1934,[1]] the phenomenon of the evaporation of moisture from a soil surface containing only hygroscopic water and the reverse phenomenon during night, *viz.*, the absorption of moisture from the air layers near the ground by the desiccated soil surface, were shown to exert a controlling influence on the distribution of moisture with height in the air layers. From observations of the moisture contents of the soil surface and of the air at different levels above ground it was found that, during the "evaporating regime" (during day), the pressure of water vapour decreased with height, whereas, during the "absorbing regime" (at night), the vapour pressure increased with height. In the preliminary studies which have been discussed in the above paper the observations were taken only twice daily with the local soil, *viz.*, at sunrise and at sunset. With a view to study the diurnal variation in the moisture content two-hourly measurements were made with representative soils from different parts of the country, the soils being exposed under identical conditions in the Agricultural Meteorological Observatory at Poona. Such measurements were conducted during the summer of 1934 as well as during the winter of 1935. Besides these, measurements of the moisture content of the surface layers of the soil in the bare ground of the Agricultural Meteorological Observatory were also made in 1935. Experiments on the absorption of moisture by dry soils and measurements of various related physical properties of typical soils were also made in the laboratory about the same time. In all these investigations the meteorological aspect has been kept in the fore-front and the soils have been used as they occur, *i.e.*, without separating them into their components by mechanical or chemical analysis. These results are discussed in the following sections :

* "Preliminary studies on soil-moisture in relation to moisture in the surface layers of the atmosphere during the clear season at Poona" by Ramdas, L. A. and Katti, M. S., *Indian Journal of Agricultural Science*, Vol. IV, part 6, 1934. (This paper will be referred to as paper 1 in the following pages.)

Section I

Experiments on the evaporation and absorption of water vapour by different soils

1. Two-hourly observations of the moisture contents of a few soils during the summer of 1934 (23rd May to 2nd June 1934)

After realising from the preliminary experiments discussed in paper I that the results indicated an interesting line of work, steps were taken (1) to pursue work with different types of soils and (2) to commence observations several times daily so as to study the diurnal variation in the moisture contents in greater detail. Although the season was well advanced and the simple climate of winter had given place to one of the sea-breeze type, there was a spell of clear weather and it was considered worth while to start comparative observations in order to see how, under similar meteorological conditions, soils differed from one another.

The observations were begun at the Agricultural Meteorological Observatory with Poona black cotton soil at 0600 hrs. on the 23rd May 1934 ; on the morning of the 25th, samples of alluvial soil from Sakrand (in Sind) were added ; on the morning of the 1st June 1934, samples of quartz powder, brown Dharwar schist and red laterite were also included. The two-hourly observations on the soil samples were continued up to 0600 hrs. on the 2nd June after which they were discontinued owing to the onset of cloudy weather.

During the above period (23rd May to 2nd June) the skies were clear but the simple climate of winter had changed to one of the " afternoon sea-breeze " type. Ordinarily, during calm weather in winter, the air sample over Poona does not change materially during the day or, often, during a series of days. The convective winds during such days cause mixing of the air layers in the vertical direction. In February and later months of the clear season the westerly sea-breeze begins to arrive at Poona about sunset. The time of arrival becomes earlier as the season advances. This breeze which replaces the land air has a higher moisture content. The sea-breeze penetrates inland slowly, dies down by midnight and later remains stagnant over the country until, after sun-rise on the next morning, the diurnal convection sets in and mixes up the shallow layer of moist air with the reservoir of dry air at the higher levels. During the sea-breeze season, *viz.*, part of February, March, April and May, the dry land air holds its sway during day time but is regularly displaced by sea-air during the night. The effect of this is seen in the psychrometric data taken at the maximum and minimum temperature epochs. These show higher vapour pressures during the night and until the next morning up to about 8 A.M., than during the day time after the convective winds have set in. During the earlier months of the season which are free from sea-breeze the mean vapour pressure is practically the same day and night. As already explained in paper 1, both during the non-sea-breeze and the sea-breeze portions of the clear season the vapour pressure increases with height during the night and decreases with height during the day.

TABLE I

Time	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700
Weight of Poona soil in grms. (Mean for 23-31 May 1934).	60·751	60·676	60·554	60·355	60·017	59·709	59·370	59·159	59·021	58·961	58·973	59·038
Weight of Sakrand soil in grms. (Mean for 25-31 May 1934).	60·435	60·379	60·321	60·256	60·197	60·144	60·104	60·074	60·053	60·041	60·034	60·043
Temperature °C. (Soil surface) . . .	22·5	27·5	35·1	44·1	52·0	57·5	60·5	61·1	59·4	56·2	51·6	45·8
Air temperature (0·3″) °C.	22·6	25·0	27·9	31·8	35·6	38·5	40·8	42·3	42·9	42·7	41·7	38·6
Air temperature °C. (one ft.) . . .	22·9	24·7	27·2	30·2	33·4	35·4	36·9	38·0	38·6	38·6	38·0	36·4
Wind speed at 1′-6″ (miles per hour) . .	4·7	5·2	5·8	6·2	6·9	7·4	8·1	8·9	8·9	8·9	9·1	9·2
Vapour pressure (0·3″) in mm. of Hg. . .	14·5	15·2	15·6	15·4	14·7	14·3	13·3	13·3	12·2	11·6	11·3	12·2
Vapour pressure (4 ft.) in mm. of Hg. . .	14·6	14·7	14·6	14·1	13·5	13·0	12·3	11·4	10·6	10·5	10·5	11·6
Humidity per cent (0·3″)	71	64	56	43	34	28	23	21	19	18	20	24

Time	1800	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500
Weight of Poona soil in grms. (Mean for 23-31 May 1934).	59·185	59·383	59·621	59·837	60·003	60·148	60·265	60·379	60·475	60·557	60·631	60·693
Weight of Sakrand soil in grms. (Mean for 25-31 May 1934).	60·061	60·089	60·123	60·168	60·199	60·226	60·253	60·276	60·301	60·321	60·342	60·361
Temperature °C (Soil surface) . . .	39·6	34·4	31·8	29·9	28·4	27·1	26·3	25·5	24·7	24·0	23·4	22·9
Air temperature (0·3″) °C.	34·4	31·6	29·1	27·4	26·1	25·4	24·8	24·4	24·2	23·7	23·2	22·9
Air temperature °C. (one ft.) . . .	33·6	31·1	28·8	27·2	26·0	25·3	24·8	24·4	24·1	23·8	23·5	23·3
Wind speed at 1′-6″ (miles per hour) . .	9·3	8·9	8·1	7·3	6·7	6·4	5·7	4·9	5·1	5·0	4·8	4·4
Vapour pressure (0·3″) in mm. of Hg. . .	13·3	14·1	14·6	15·3	15·6	15·4	15·0	15·2	15·2	15·2	15·2	15·2
Vapour pressure (4 ft.) in mm. of Hg. . .	13·0	13·8	15·0	15·9	16·3	16·1	15·9	15·8	15·8	15·6	15·4	15·4
Humidity per cent (0·3″) . . .	32	40	48	56	61	63	64	66	67	69	72	70

The soil samples, weighing about fifty grammes each, were exposed in small aluminium vessels having a cross-section of 30 sq. cm. The vessels were embedded in the ground so as to bring the level of the soils inside flush with that of the soil outside. In the case of the soils of Poona and Sakrand, the samples were exposed in duplicate ; only one sample each of the other soils was used. The two-hourly observations consisted of the following measurements :—

(*a*) the weight of each soil sample (the vessels were kept tightly covered during weighing which was done quickly on a good physical balance),

(*b*) air temperature, humidity and vapour pressure at several levels starting from the soil surface (with an Assmann psychrometer),

(*c*) wind speeds at 1½ ft. and 6 ft.,

(*d*) soil temperature at the surface of the soil, and

(*e*) the intensity of the total radiation from the sun and the sky from the records of the Moll solarigraph.

In studying these data it was convenient to plot the observations against the actual times at which they were made and from these curves to read off the hourly values. Table 1 gives the mean hourly weights of the Poona soil (mean for the period 23rd to the 31st May 1934) and the Sakrand soil (mean for the period 25th to the 31st May 1934). The hourly variations shown by the duplicate samples agree very closely and the figures in the table are the averages obtained from the duplicate samples. The mean hourly data of the following meteorological factors are also given in Table I :—

(*i*) soil-surface temperature in °C.,

(*ii*) air temperature at 0·3″ above the ground,

(*iii*) air temperature at 1 ft. above the ground,

(*iv*) the percentage humidity at 0·3 in. and the pressure of water vapour in mm. of Hg. of the air at 0·3″ and 4 ft. above the ground, and

(*v*) the velocity of wind at 1 ft. 6 in. above the ground (in miles per hour).

The hourly data bring out the characteristics of the phenomena under consideration in much greater detail than the data recorded at sunrise and at sunset and given in Table VII of paper 1. It may be noted that the soils have their *minimum* moisture content about the epoch of maximum temperature and their *maximum* moisture content at the epoch of minimum temperature. The results are easier to visualise when represented diagrammatically (Fig. 1). The epochs of *maximum air temperature, minimum saturation* of air with water vapour (humidity per cent) and *minimum water vapour content* in the air (this would be maximum water vapour content during days of no sea-breeze, *e.g.*, December, January, when we deal with the same air samples) occur practically at the same time as the epoch of *minimum* moisture content of the soil samples. During months with no sea-breeze the maximum wind velocity would also have occurred about the same time.

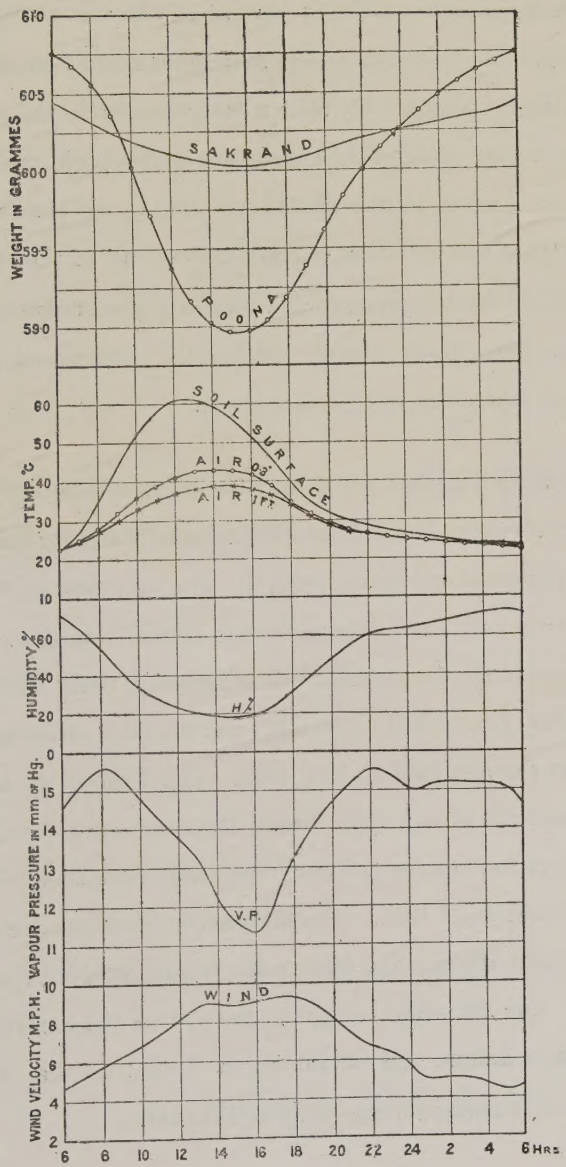

WEIGHT IN GRAMMES
610
605
600
595
590
SAKRAND
POONA
TEMP. °C
60
50
40
30
20
10
SOIL SURFACE
AIR 0'
AIR 1FT.
HUMIDITY %
60
40
20
0
H%
WIND VELOCITY M.P.H. VAPOUR PRESSURE IN mm OF Hg.
15
14
13
12
11
10
9
8
6
4
2
V.P.
WIND
6 8 10 12 14 16 18 20 22 24 2 4 6 HRS.

Fig. 1.

The epoch of *maximum moisture content* of the soil samples coincides with the epoch of minimum temperature and maximum saturation of the air with water vapour. As already pointed out, the air layer nearest to the ground would have a smaller water vapour content than the layers higher up in the early morning, but this is somewhat masked by the disturbance due to sea-breeze during the night. It is significant that the variation of moisture content of the soil is in phase with the variation of the air temperature and humidity percentage rather than the soil surface temperature (which closely follows the altitude of the sun and has a maximum value when the sun is over-head).

The other interesting fact which may be observed from Fig. 1 is that the diurnal variation of moisture in the Poona soil is more than four times that of the soil from Sakrand [Ramdas and Katti, 1934,[2]]. The very first day's results suggested that each soil type may show a characteristic diurnal variation. This expectation has been borne out by the observations recorded in June 1934 (0600 hrs. of 1st June 1934 to 0600 hrs. of 2nd June 1934) and the later observations made during the clear season October 1934 to May 1935. Fig. 2 shows the hourly variation of the moisture contents of soils from Poona, Dharwar and Sakrand, a sample of red laterite and a sample of quartz powder respectively from 0600 hrs. of 1st June 1934 to 0600 hrs. of 2nd June 1934. The sample of quartz powder did not show any variation of weight whereas the other soils showed different diurnal variations in their weights. The maximum weight of the soil (in the morning) when its moisture content is maximum and the minimum weight (in the afternoon) when its moisture content is minimum are given in Table II.

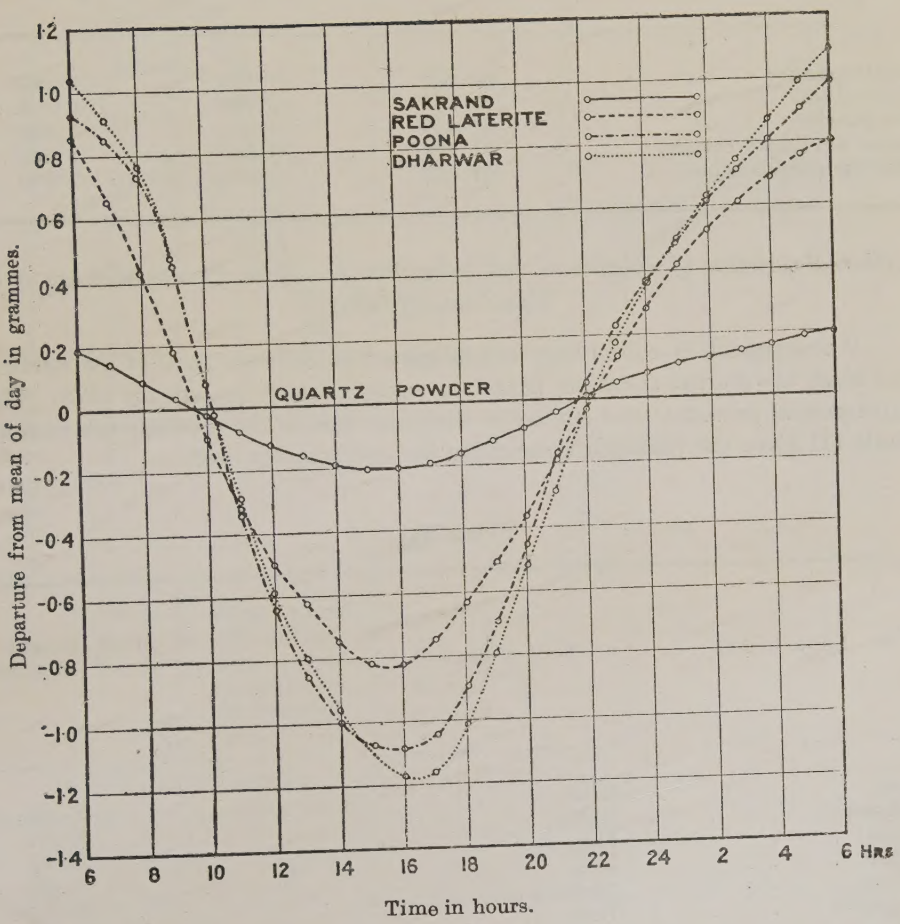


Fig. 2. Hourly variation of moisture-content of five different soils (0600 hours of 1st June 1934 to 0600 hours of 2nd June 1934).

TABLE II

Name of soil	Maximum weight (morning) grms.	Minimum weight (afternoon) grms.	Diurnal range of moisture content grms.
Quartz powder	60·610	60·610	0·000
Sakrand soil	60·575	60·160	0·415
Red laterite	61·080	59·390	1·690
Poona soil (black cotton)	61·400	59·350	2·050
Dharwar (brown schist)	61·450	59·220	2·230

2. Diurnal variation of moisture in eight soils (0600 hrs. of the 22nd to 0600 hrs. of the 23rd January 1935)

It was possible to collect more soil samples from different parts of the country and study the diurnal variations in their moisture contents in January 1935. The experimental procedure was similar to that described in the previous sub-section. Table III gives the particulars regarding the soil samples used.

TABLE III

Name of soil	Colour of the soil	Area of cross-section of vessels used for exposing the samples	Mean weight of soil in grms
Poona	Black	12·6 sq. cm.	30·16
Sholapur	Black	,,	30·46
Hagari	Dark	,,	29·75
Ranchi	Red	,,	29·90
Jhelum	Reddish grey	,,	30·31
Bangalore	Red	,,	30·46
Pusa	Grey (alluvial)	,,	29·75
Lyallpur	Dark-grey	,,	30·33

The hourly weights of these soil samples, when exposed to identical weather conditions from 0600 hrs. of the 22nd to 0600 hrs. of the 23rd January 1935, as well as their departures from the respective mean weights are given in Table IV. Fig. 3 which shows these results diagrammatically confirms the features shown by Fig. 2.

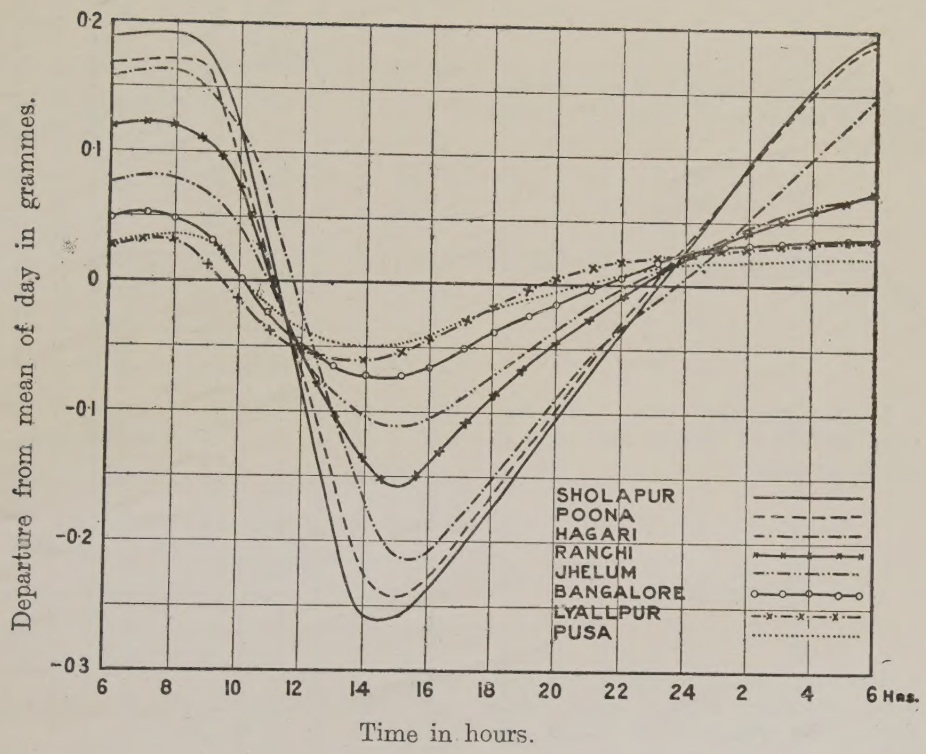


Fig. 3. Hourly variation of moisture-content of eight different soils.

On this day there were traces of clouds in the afternoon which decreased rapidly towards the evening, the night being practically clear. The hourly march of soil temperature, air temperature, humidity percentage, pressure of water vapour, wind and cloudiness are shown in Fig. 4. Apart from the slight cloudiness in the afternoon the day was one of the winter type without any sea-breeze. The stratification of the air layers at night (coldest air being a few inches above the ground and then temperature increasing with height) was undisturbed. The reversal of the vapour pressure gradient may be seen in Fig. 4. The nocturnal desiccating influence of the soil on the air layers near it is also clearly seen.

Temperature in °C. of soil surface and of air at 0·3″ and 1′ above surface.

Humidity percentage at 0·3″ above ground.

Vapour pressure (mm. of Hg.) near surface of ground and at 6 ft. above ground.

Wind velocity m.p.h.

Duration of clear skies. If sunshine recorder shows clear skies during the whole of an hour the value is 1·0, if cloudy the value is 0·0.

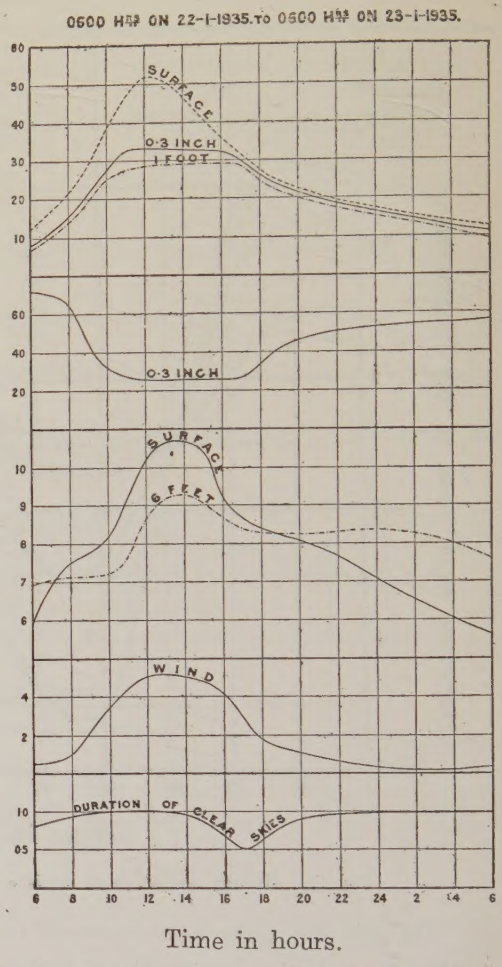


Fig. 4. Hourly variation of meteorological factors (0600 hours of 22nd January 1935 to 0600 hours of 23rd January 1935).

Table IV

Time in hours (I. S. T.)	Poona soil		Sholapur soil		Hagari soil		Ranchi soil (Plot 4)		Jhelum soil (305/1930)		Bangalore soil		Pusa soil		Lyallpur soil	
	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day
0600	54·705	0·161	59·115	0·186	60·395	0·156	56·176	0·119	56·745	0·076	64·660	0·049	68·443	0·028	58·876	0·027
0700	54·710	0·166	59·120	0·191	60·400	0·161	56·180	0·123	56·750	0·081	64·665	0·054	68·446	0·031	58·880	0·031
0800	54·719	0·175	59·120	0·191	60·400	0·161	56·177	0·120	56·750	0·081	64·660	0·049	68·455	0·040	58·880	0·031
0900	54·710	0·166	59·105	0·176	60·385	0·146	56·165	0·108	56·738	0·069	64·648	0·037	68·451	0·036	58·862	0·013
1000	54·635	0·091	59·045	0·116	60·355	0·116	56·123	0·076	56·714	0·045	64·615	0·004	68·416	0·001	58·835	—0·014
1100	54·560	0·016	58·955	0·026	60·290	0·051	56·060	0·003	56·666	—0·003	64·585	—0·026	68·395	—0·020	58·805	—0·044
1200	54·482	—0·062	58·850	—0·079	60·214	—0·025	56·000	—0·057	56·612	—0·057	64·564	—0·047	68·380	—0·035	58·793	—0·056
1300	54·395	—0·149	58·745	—0·184	60·145	—0·094	55·961	—0·096	56·585	—0·084	64·546	—0·065	68·368	—0·047	58·790	—0·059
1400	54·320	—0·224	58·670	—0·259	60·080	—0·159	55·920	—0·137	56·564	—0·105	64·540	—0·071	68·368	—0·047	58·790	—0·059
1500	54·300	—0·244	58·670	—0·259	60·030	—0·209	55·900	—0·157	56·558	—0·111	64·540	—0·071	68·368	—0·047	58·799	—0·050
1600	54·314	—0·230	58·700	—0·229	60·033	—0·206	55·920	—0·137	56·567	—0·102	64·546	—0·065	68·377	—0·038	58·811	—0·038
1700	54·347	—0·197	58·726	—0·203	60·061	—0·178	55·955	—0·102	56·582	—0·087	64·561	—0·050	68·386	—0·029	58·820	—0·029
1800	54·380	—0·164	58·756	—0·173	60·090	—0·149	55·970	—0·087	56·600	—0·069	64·579	—0·032	68·395	—0·020	58·829	—0·020
1900	54·416	—0·128	58·790	—0·139	60·120	—0·119	55·992	—0·065	56·615	—0·054	64·591	—0·020	68·402	—0·013	58·844	—0·005
2000	54·455	—0·089	58·826	—0·103	60·154	—0·085	56·012	—0·045	56·636	—0·033	64·603	—0·008	68·410	—0·005	58·856	—0·007

TABLE IV—*contd.*

Poona soil			Sholapur soil		Hagari soil		Ranchi soil (Plot 4)		Jhelum soil (305/1930)		Bangalore soil		Pusa soil		Lyallpur soil	
Time in hours (I. S. T.)	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day
2100	54·500	—0·044	58·868	—0·061	60·187	—0·052	56·030	—0·027	56·654	—0·015	64·615	0·004	68·415	0·000	58·862	0·013
2200	54·525	—0·019	58·904	—0·025	60·202	—0·037	56·048	—0·009	56·666	—0·003	64·620	0·009	68·428	0·013	58·868	0·019
2300	54·551	0·007	58·934	0·005	60·220	—0·019	56·066	0·009	56·681	0·012	64·630	0·019	68·428	0·013	58·871	0·022
2400	54·575	0·031	58·964	0·035	60·250	0·011	56·078	0·021	56·693	0·024	64·640	0·029	68·431	0·016	58·871	0·022
0100	54·600	0·056	58·988	0·059	60·268	0·029	56·090	0·033	56·705	0·036	64·640	0·029	68·434	0·019	58·877	0·028
0200	54·626	0·082	59·021	0·092	60·295	0·056	56·099	0·042	56·717	0·048	64·642	0·031	68·434	0·019	58·880	0·031
0300	54·655	0·111	59·054	0·125	60·316	0·077	56·108	0·051	56·726	0·057	64·642	0·031	68·435	0·020	58·884	0·035
0400	54·685	0·141	59·084	0·155	60·340	0·101	56·120	0·063	56·732	0·063	64·648	0·037	68·436	0·021	58·886	0·037
0500	54·710	0·166	59·102	0·173	60·364	0·125	56·126	0·069	56·738	0·069	64·649	0·038	68·438	0·023	58·886	0·037
0600	54·722	0·178	59·120	0·191	60·385	0·146	56·138	0·081	56·742	0·073	64·649	0·038	68·440	0·025	58·886	0·037
Mean of day	54·544		58·929		60·239		56·057		56·669		64·611		68·415		58·849	

We may now combine the results of Tables I and IV and calculate the moisture variation index of different types of soils (diurnal range of moisture content expressed as a ratio of the diurnal range of the Poona soil). The values of this coefficient are given in Table V for all the soils which have been experimented with.

TABLE V

Name of soil	Moisture variation index (Poona=1)
Poona black cotton soil	1·00
Dharwar black cotton soil	1·10
Sholapur black soil	1·04
Hagari	0·86
Red laterite	0·81
Ranchi	0·65
Jhelum	0·44
Bangalore	0·29
Pusa (alluvial)	0·20
Lyallpur (alluvial)	0·21
Sakrand (alluvial)	0·19
Quartz powder	0·00

The above table shows that the black cotton soils undergo the maximum diurnal variation of moisture content owing to the loss of water by evaporation during the day and gain by absorption from the air during the night. The brown and red soils come next. The alluvial soils from the Indo-Gangetic as well as the Sind areas show a diurnal variation which is only a fifth of that of the black cotton soils. The sample of quartz powder comes at the bottom of the list with no variation. It is indeed remarkable that soils from places at large distances apart show very similar features so long as they belong to the same soil group [Ramdas and Katti, 1935,[1]]. We shall discuss this point at greater length in a later section.

3. Diurnal range of the moisture content of Poona soil as estimated from actual samples taken daily from the soil surface during the period 22nd January 1935 to 5th March 1935

The hourly variation of the moisture content of soil samples discussed in the two previous sub-sections clearly shows that the epochs of maximum and minimum water contents coincide with the epochs of minimum and maximum air temperature respectively. In Table VIII of paper 1 we have indicated the results of earlier estimations of the moisture content of the soil samples taken from the surface at sunrise and at sunset respectively. In view of the more precise information regarding the epochs of maximum and minimum moisture contents of the soil (which shows that the time of minimum moisture content is much earlier than sunset time) available from the investigations described above, it was considered

worth whileto make daily estimations of the moisture contents of soil samples taken from the surface of the bare soil of the Agricultural Meteorological Observatory at 0630 hrs. and 1530 hrs. I. S. T. respectively in order to find out how the diurnal range of the moisture-content varied from day to day. Such daily estimations were made from the 22nd January to the 5th March 1935. The results are given in Table VI. The moisture-contents are here expressed as percentages of the weight of the dry soil. The differences between these percentages are quite large and systematic. The average moisture content in the morning during the whole period is 7·79 per cent whereas that in the afternoon is 3·80 per cent and the difference of nearly four per cent shows how large is the diurnal variation. This diurnal variation is in agreement with the value obtained by experiments with the soil inside a vessel (Tables II and IV), thus showing that the results of all these experiments support each other satisfactorily.

TABLE VI

Moisture percentage in samples from surface soil taken in the morning and evening at about 6-30 A.M. and 3-30 P.M. respectively

Date	A.M.	P.M.	Date	A.M.	P.M.
22nd Jan. 1935	9·81	5·20	12th Feb. 1935	6·95	3·40
23rd „ 1935	9·12	5·07	13th „ 1935	7·12	3·55
24th „ 1935	8·78	3·82	14th „ 1935	7·83	3·20
25th „ 1935	9·54	5·48	15th „ 1935	7·04	3·06
26th „ 1935	9·23	4·91	16th „ 1935	6·81	3·22
27th „ 1935	8·94	5·06	17th „ 1935	6·78	2·93
28th „ 1935	9·42	5·23	18th „ 1935	6·91	3·30
29th „ 1935	9·45	5·84	19th „ 1935	7·35	3·31
30th „ 1935	8·53	4·21	20th „ 1935	7·22	2·81
31st „ 1935	8·84	5·32	21st „ 1935	6·81	3·64
1st Feb. 1935	9·01	4·92	22nd „ 1935	7·00	3·25
2nd „ 1935	8·62	4·00	23rd „ 1935	6·92	2·89
3rd „ 1935	8·53	4·12	24th „ 1935	6·65	2·54
4th „ 1935	8·04	3·55	25th „ 1935	7·21	3·12
5th „ 1935	7·85	4·05	26th „ 1935	7·13	3·32
6th „ 1935	8·13	4·93	27th „ 1935	7·55	3·34
7th „ 1935	7·32	3·94	28th „ 1935	7·08	3·26
8th „ 1935	7·52	3·41	1st Mar. 1935	6·98	3·15
9th „ 1935	6·84	3·23	2nd „ 1935	7·35	2·94
10th „ 1935	7·21	3·30	3rd „ 1935	7·21	3·30
11th „ 1935	7·32	3·89	4th „ 1935	7·43	3·12
			5th „ 1935	7·51	3·43

Fig. 5 gives the hourly values of the moisture content of the surface soil as estimated on 22nd January 1935. The similarity of the hourly march as shown by this figure to that seen in Figures 1, 2 and 3 is quite striking.

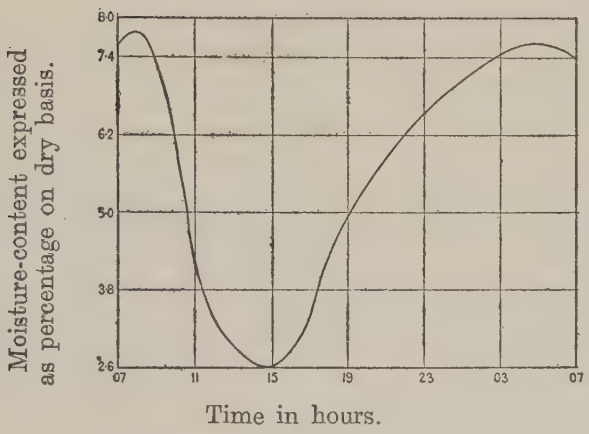


Fig. 5. Hourly variation in the moisture-content of the surface soil (in the open field) on 22nd January 1935.

4. Diurnal variation in the moisture-content of Poona soil in relation to its depth below the soil surface

We have established the following facts in the previous sub-sections : —

(1) there is a conspicuous exchange of moisture between the soil surface and the air layers above it,

(2) the intensity of this exchange is a characteristic property of each soil, and

(3) the epochs of maximum and minimum moisture contents of the soil coincide with those of minimum and maximum temperatures respectively.

In the experiments with samples kept in vessels the soil and the air layers form the two components in the system. Under actual field conditions, however, we have to investigate whether the layers below the surface play any important part in the moisture balance at the surface during clear weather. The problem is much simplified by the fact that, in the Bombay-Deccan, there is no water table which would affect the soil layers near the surface, because the surface layers are resting above hard rock or *murram* and the water table is several feet below. The question whether the soil immediately below the surface makes any measurable contribution of moisture to the surface during the day can be settled easily by taking samples from different depths at intervals during the day and estimating their moisture contents. If there is a significant diurnal variation of the moisture contents at these depths, then it will be necessary to conclude that these layers do take part in the moisture balance at the surface.

Table VII

Diurnal variation of soil-moisture (per cent on dry basis) at different depths and of contemporary meteorological factors from 0600 hrs. of 19th February 1935 to 0600 hrs. of 20th February 1935

Time	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700
Percentage moisture at surface	7·0	7·2	6·8	5·9	5·1	4·3	3·7	3·1	2·6	2·7	2·9	3·2
Percentage moisture at 1″ depth	7·6	7·5	7·7	7·5	8·0	8·2	8·3	8·4	8·2	7·9	7·7	7·7
Percentage moisture at 6″ depth	25·7	25·6	25·7	25·0	25·2	25·5	25·0	25·4	25·7	25·8	25·8	25·7
Vapour pressure (0·3″) mm. of Hg.	7·4	7·5	7·9	9·7	11·0	9·0	7·5	6·5	5·8	4·5	2·7	2·7
Vapour pressure (6 ft.) mm. of Hg.	7·8	7·7	7·6	7·4	6·9	5·5	5·0	5·3	5·5	3·8	3·3	3·3
Humidity per cent (0·3″)	65	65	63	52	38	26	20	16	13	10	6	5
Humidity per cent (6 ft.)	66	64	60	52	37	25	19	18	15	12	10	10
Wind speed (in miles per hour)	0·5	0·6	1·0	1·2	1·5	3·6	4·7	4·7	4·4	3·6	2·6	2·1

Time	1800	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500	0600
Percentage moisture at surface	3·5	3·8	4·2	4·6	4·8	4·9	5·1	5·2	5·3	5·3	5·4	5·6	5·9
Percentage moisture at 1″ depth	8·3	8·0	8·0	7·9	7·6	7·3	7·4	7·5	7·7	7·6	7·8	8·0	7·9
Percentage moisture at 6″ depth	25·6	25·3	24·9	24·8	25·5	25·8	25·9	25·9	25·9	25·7	25·5	25·2	25·0
Vapour pressure (0·3″) mm. of Hg.	3·4	3·3	4·0	3·9	4·0	4·1	3·9	3·8	3·5	3·3	3·1	2·8	2·9
Vapour pressure (6 ft.) mm. of Hg.	3·7	3·7	4·0	4·3	4·7	5·1	5·0	4·9	4·8	4·6	4·5	4·4	4·2
Humidity per cent (0·3″)	9	15	19	22	26	29	31	33	34	34	35	35	36
Humidity per cent (6 ft.)	12	15	20	24	32	36	39	42	44	46	47	48	48
Wind speed (in miles per hour)	1·3	1·0	0·8	0·6	0·4	0·3	0·2	0·1	0·1	0·2	0·1	0·1	0·1

TABLE VIII

Diurnal variation of soil-moisture (percentage on dry basis) at different depths and of contemporary meteorological factors from 0600 hrs. of 6th May 1935 to 0600 hrs. of 7th May 1935.

Time	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700
Percentage moisture at surface . . .	6·8	6·6	6·4	5·7	5·3	4·7	4·3	4·0	3·7	3·6	3·9	4·2
Percentage moisture at 1″ depth . . .	7·8	7·6	7·6	7·8	7·9	8·0	8·0	7·8	7·7	7·4	7·3	7·0
Percentage moisture at 6″ depth . . .	20·2	20·4	20·7	20·6	20·6	20·5	20·4	20·4	20·6	20·7	21·0	20·3
Vapour pressure (0·3″) mm. of Hg. . .	9·5	10·4	11·5	11·0	9·7	8·3	8·0	7·8	7·2	4·5	4·5	8·0
Vapour pressure (6 ft.) mm. of Hg. . .	10·9	10·5	9·9	9·0	7·7	6·6	6·0	5·4	4·9	4·4	5·0	8·1
Humidity per cent (0·3″)	53	47	34	24	17	11	9	9	7	4	5	12
Humidity per cent (6 ft.)	56	51	35	24	17	13	11	9	8	7	9	16
Wind speed (in miles per hour) . . .	0·5	0·5	0·8	1·5	2·7	3·5	4·2	4·6	5·1	5·3	4·2	5·0

Time	1800	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500	0600
Percentage moisture at surface . . .	4·5	5·0	5·5	5·8	6·1	6·3	6·6	6·8	7·0	7·2	7·3	7·5	7·5
Percentage moisture at 1″ depth . . .	6·8	6·8	6·8	7·0	7·3	7·2	7·4	7·3	7·3	7·5	7·1	7·4	7·6
Percentage moisture at 6″ depth . . .	20·0	20·3	20·6	20·9	21·0	20·9	20·9	20·8	20·7	20·7	20·6	20·6	20·5
Vapour pressure (0·3″) mm. of Hg. . .	14·5	15·7	16·4	16·7	16·9	16·7	16·4	15·8	15·4	14·8	14·4	13·7	13·5
Vapour pressure (6 ft.) mm. of Hg. . .	14·1	17·5	18·5	18·8	18·1	17·2	16·7	16·4	16·0	15·6	15·2	14·9	14·6
Humidity per cent (0·3″)	25	37	46	51	53	54	55	56	56	57	57	57	55
Humidity per cent (6 ft.) . .	27	40	47	56	56	56	57	57	58	58	58	59	59
Wind speed (in miles per hour) . . .	7·7	8·5	8·5	7·5	6·2	5·6	5·1	4·6	4·2	3·8	3·4	2·8	2·4

Experiments to verify this point were made from 19th to 20th February and 6th to 7th May 1935. Soil samples (in duplicate) were taken simultaneously from the surface, one inch and 6 in. below the surface at two-hourly intervals and their moisture-contents determined in the usual manner. Measurements of the meteorological factors were also made simultaneously, and are given in Tables VII and VIII respectively. The moisture-contents of the soil at the three depths and for different hours on these two occasions are shown in Figs. 6 and 7 respectively. The curves in these figures clearly show that the diurnal variation is insignificant except at the surface.

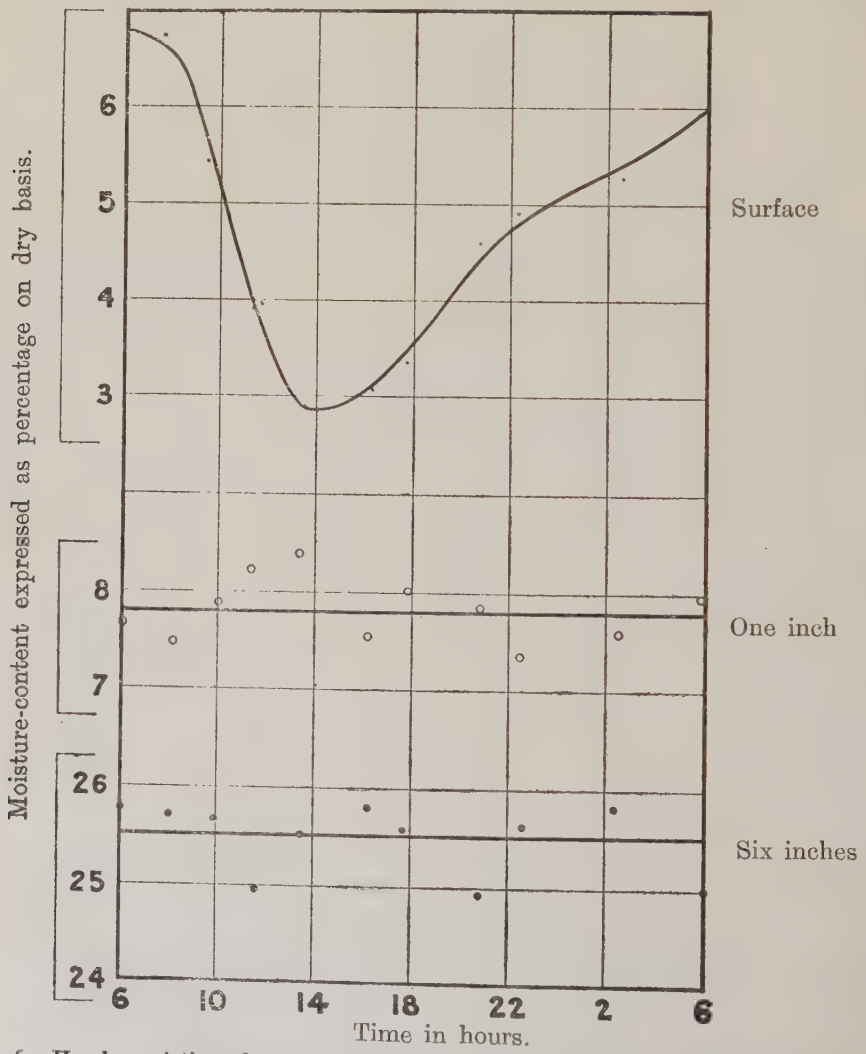


Fig. 6. Hourly variation of moisture-content at "surface", 1" and 6" depths (0600 hours of 19th February 1935 to 0600 hours of 20th February 1935).

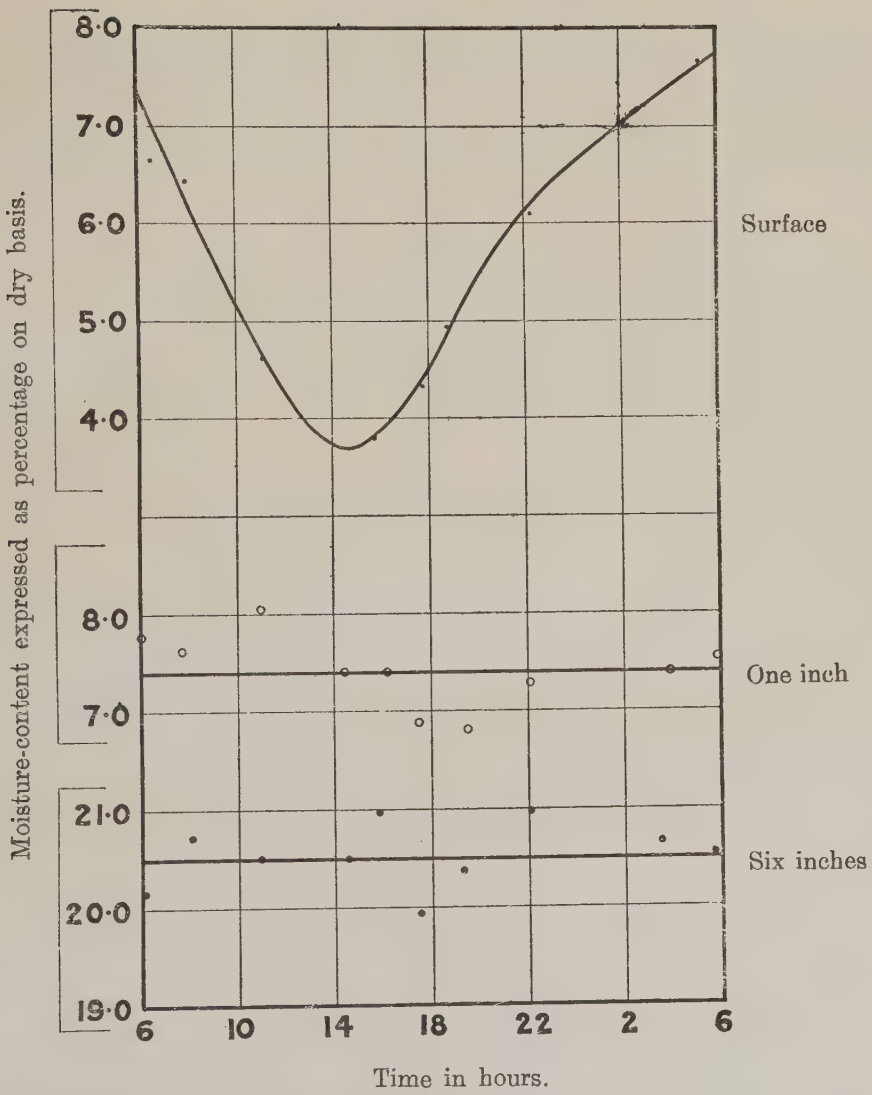


Fig. 7. Hourly variation of moisture-content at "surface", 1″, 6″ depths (0600 hours of 6th May 1935 to 0600 hours of 7th May 1935).

The soil layers below an inch may, therefore, be assumed to have no influence on the hourly variation of moisture at the surface during the clear season. We are thus concerned in the present discussion mainly with the soil surface and the air layers above it.

It is, of course, to be expected that, in tracts where the water table is very near the surface, *e.g.*, coastal tracts of India and tracts near irrigation canals as in the Punjab and in Sind, the water in the soil below the surface would play a most important role in the moisture balance at the surface of the soil. Phenomena of this type would be quite distinct from what we have been discussing in this paper and deserve a special study.

Section II

The moisture-variation index in relation to other properties of the soil

The results of chemical and mechanical analyses of the main soil types in India are available in the publications of the various agricultural departments. The data are by no means exhaustive or derived according to a common plan or method. Nevertheless, an examination of these data reveals that one of the major variations from soil to soil is in the clay fraction. Table IX gives the results of mechanical analyses of certain typical soils. The table shows that, in general, the alluvial group has a small clay fraction and large silt content, the black soils are rich in clay and poorer in the particles of large size, other soils having intermediate positions in the scale of clay content. It is well known that, the larger the clay fraction or colloidal matter in a medium like the soil, the larger will be the effective area available for absorptive phenomena, so that, in a general way, it is easy to see why black cotton soils should have the largest moisture-variation index.* The study of the moisture-variation index in the case of the different groups of particle sizes would certainly be worth-while in the case of the major soils of India as a special investigation. In the present section we shall confine ourselves to the results of some preliminary experiments on the physical properties of the soils which were made recently at Poona.

TABLE IX

Name of soil types	District	Clay	Fine silt	Silt	Fine sand	Coarse sand	Remarks
1. Black cotton soils	South Gujarat .	44·4	8·1	26·5	20·7	0·4	Taken from bulletin No. 160, 1929 "Soils of the Bombay Presidency."
	Jalgaon .	49·1	4·0	17·1	25·6	4·1	
	Surat .	32·3	6·4	34·8	26·3	0·2	
	West Khandesh	42·8	8·7	32·1	14·1	4·1	
	Poona .	25·7	8·1	33·3	25·9	7·0	
	Nagpur .	44·4	18·3	12·8	5·5	0·4	Data supplied by Agricultural Department, Central Provinces.
	Akola .	36·9	19·1	15·8	8·5	2·6	
	Wardha .	40·0	21·7	11·2	7·3	0·4	

* "A Study of Absorption of Moisture by Soil" by J. N. Sen, Ph. D., and B. M. Amin, B.A., Memoirs of the Department of Agriculture in India (Chemical Series), Vol. 8, No. 12, 1926, is very interesting in this connection.

TABLE IX—(*contd.*)

Name of soil types	District	Clay	Fine silt	Silt	Fine sand	Coarse sand	Remarks
2. Laterite and red soils	Poona (from hill sides).	4·0	3·9	19·9	18·3	13·3	From bulletin No. 160, Department of Agriculture, Bombay Presidency.
	Dacca .	28·1	13·5	24·5	21·2	4·0	Data supplied by Agricultural Department, Bengal.
	Mandalay	10·0 22·3 10·8	21·1 16·0 21·0	23·2 23·8 25·9	39·3 33·6 33·1	5·5 4·0 9·2	Taken from Agricultural Survey No. 15 of 1932, Department of Agriculture, Burma.
3. Alluvial soils	Sind .	15·7	8·5	56·1	19·5	0·2	From bulletin No. 160, Department of Agriculture, Bombay Presidency.
	Punjab (average of typical districts).	12·3	21·2	20·7	30·0	12·0	From Memoirs of the Department of Agriculture in India, " Soils of the Punjab ", Vol. X, No. 2.
	Bengal .	14·1	20·5	26·1	27·8	1·24	Data supplied by Department of Agriculture, Bengal.

1. Water-holding capacity

The water-holding capacities of soils from Poona, Sholapur, Hagari, Bangalore, Pusa and Lyallpur were determined with the help of portable drain-gauges designed locally. Plate LXVI is a photograph of this type of drain-gauge which consists of a cylindrical vessel of the required height and 5 inches in diameter (same as that of the standard rain-gauge) to contain the soil and a funnel which drains the water percolating through the soil into a suitable receiver below. The soil rests on a perforated disc at the bottom of the cylindrical vessel.

In our experiments 6″ of each soil were packed uniformly at the mean rate of 17½ oz. per inch of depth. After all the gauges were filled with the different soils, one inch depth of water was poured at the top of the soil at 1400 hrs. daily and any percolated water measured on the succeeding day at the same time. These experiments were continued without break until the soils were saturated with water when they began to drain all the water poured at the top of the soil columns.

The cylindrical vessels of the drain gauges were kept covered carefully to prevent loss of water by evaporation, the covers being removed only momentarily daily once for pouring water.

Table X gives the results of one of these experiments. After pouring one inch of water on the 4th and 5th December 1934, no percolation was noticed through any of the soils. After pouring one inch on the 6th, the Lyallpur soil showed on the 7th at 1400 hours a percolation of 0·88 in., Bangalore 0·69 in., Pusa 0·62

in., and Hagari 0·22 in. The Sholapur and Poona soils still showed no percolation. The addition of one inch on the 7th started percolation in these two also so that, after the 8th, the soils all began to percolate all the water poured at the top. From these results simple subtraction of the total percolation from the total water added during the period of the experiment gives the quantity of water "held" by the soil in each case. The water-holding capacities so measured are expressed as percentage of air-dry soil in Table XI. Here also the black cotton soils top the list.

TABLE X

Date	Depth of water poured into each gauge at 1400 hrs.	Amount of water which had percolated through the soil during 24 hours ending 1400 hours of the next day					
		Shola-pur	Poona	Hagari	Pusa	Banga-lore	Lyall-pur
4th December 1934 . .	One inch	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
5th December 1934 . .	,,	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
6th December 1934 . .	,,	*Nil*	*Nil*	0·22″	0·62″	0·69″	0·88″
7th December 1934 . .	,,	0·31″	0·38″	0·99″	0·99″	0·96″	0·96″
8th December 1934 . .	,,	1·00″	0·97″	0·99″	0·99″	0·97″	0·96″

TABLE XI

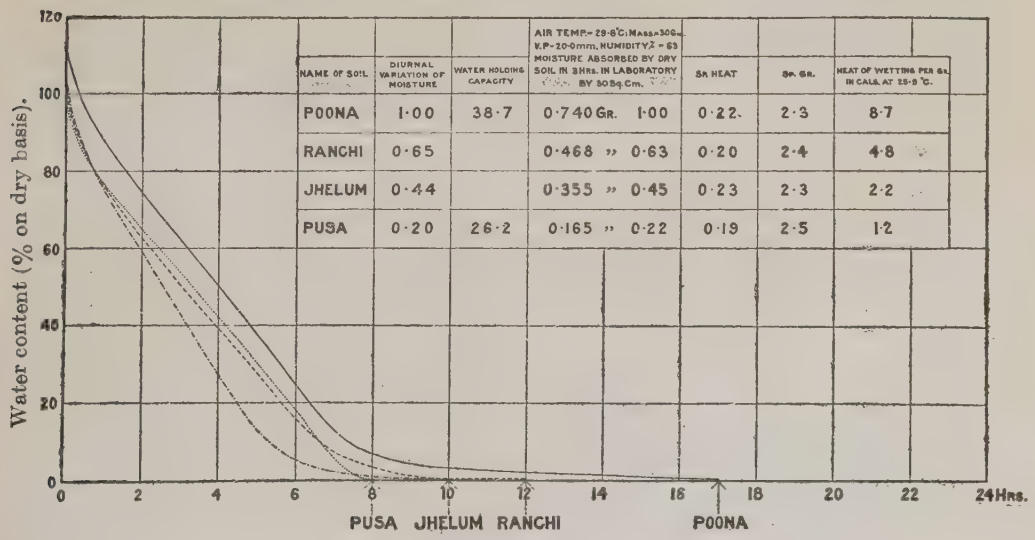
Name of soil	Depth Inches	Amount of soil per inch of depth Oz.	Total amount of water (in inches) required for saturation Inches	Water-holding capacity expressed as percentage on air-dry basis
Sholapur . .	6	17·5	3·69	41·0
Poona . . .	6	17·5	3·65	38·7
Hagari . . .	6	17·5	2·80	30·9
Pusa . . .	6	17·5	2·40	26·2
Bangalore . .	6	17·5	2·38	24·0
Lyallpur . .	6	17·5	2·20	22·8

2. Rate of drying

For determining the moisture-content of a soil sample, the sample is first weighed and kept in a steam oven until it has lost all the moisture it can give up at 100°C. This is usually verified by weighing until successive weights are

constant. An exact study of the rate of drying in a steam oven should be interesting both from a practical point of view as well as from the point of view of this paper.

Four typical soils, *viz.*, Poona, Ranchi, Jhelum and Pusa soils, were chosen for such a study ; 30 grms. of each of these soils were mixed with about the same weight of water and kept in the steam oven at the same time after weighing initially. The vessels were weighed at hourly intervals, care being taken to keep them air-tight while weighing. The hourly weighings were discontinued in each case after the particular soil had attained a constant minimum weight at 100°C. The rate of drying as well as the total time taken by each of the soils for complete drying at 100°C. will be seen from the curves in Fig. 8. The curves show that, when the soils have about 100 per cent water on dry basis, the rate of drying is rapid until the water content goes down to about 90 per cent. Later, the soils go on drying at a small but uniform rate until the moisture-content decreases to about 5 per cent. Further decrease in the moisture-content takes the least time in the case of the Pusa soil and most time in the case of Poona soil, the other soils taking an intermediate position between these.



AIR TEMP.- 28·8°C; MASS=30Gr., V.P.-20·0mm, HUMIDITY% = 63

NAME OF SOIL	DIURNAL VARIATION OF MOISTURE	WATER HOLDING CAPACITY	MOISTURE ABSORBED BY DRY SOIL IN 3Hrs. IN LABORATORY BY 50Sq.Cm.	SP. HEAT	SP. GR.	HEAT OF WETTING PER Gr. IN CALS. AT 15·5 °C.
POONA	1·00	38·7	0·740Gr. 1·00	0·22	2·3	8·7
RANCHI	0·65		0·468 » 0·63	0·20	2·4	4·8
JHELUM	0·44		0·355 » 0·45	0·23	2·3	2·2
PUSA	0·20	26·2	0·165 » 0·22	0·19	2·5	1·2

Fig. 8. The curves in the figures show the rates of drying of four different types of soils at 100°C. The inset table gives :—

(*a*) the diurnal variation of moisture-content (expressed in terms of Poona =1),

(*b*) the water-holding capacity,

(*c*) the absorption of moisture in 3 hours under steady conditions in the laboratory,

(*d*) the specific heat,

(*e*) the specific gravity, and

(*f*) the heat of wetting of the above soils.

Water content of soil (% on dry basis).

Further experiments indicated that the initially rapid drying is due to evaporation as from a free water surface at 100°C., the later steady but less rapid drying is due to evaporation of the capillary water from the moist soil and the last stage (after about the 5 per cent stage) is due to evaporation of the hygroscopic water. Pusa soil takes eight hours, Jhelum soil ten hours, Ranchi soil twelve hours and Poona soil seventeen hours to attain a steady minimum weight after complete drying at 100 °C. These times are in the same order as the moisture-variation indices given in the inset table of Fig. 8.

3. Rates of absorption of moisture under steady conditions in the laboratory

The experiments described in the first section of this paper were made in the open with soils exposed to the diurnal variations of the various meteorological factors. In order to verify whether the soils would show the same sequence in their power to absorb moisture under the steady conditions inside the laboratory, as they do with respect to their moisture-variation indices in the open, experiments were made with four typical soils, *e.g.*, Poona, Ranchi, Jhelum and Pusa soils. About thirty gr. of each of these soils which had been previously dried completely at 100°C., were exposed after they had attained room temperature to the still air of the laboratory in vessels having an area of cross-section of 30 sq. cms., at room temperature. The air temperature was 29·8°C., the partial pressure of water vapour 20·0 mm. and the percentage humidity 63 per cent. Under these conditions the Poona soil absorbed 0·740 gr. of moisture, the Ranchi soil absorbed 0·468 gr. of moisture, the Jhelum soil absorbed 0·355 gr. of moisture and the Pusa soil 0·165 gr. of moisture in three hours. Expressed in terms of Poona soil equal to 1, these absorption are in the ratio of 1 : 0·63 : 0·45 : 0·22, which is practically identical with the ratio of the moisture-variation indices as given in Table V.

4. Specific gravity

The true specific gravity of soils from Poona, Ranchi, Jhelum and Pusa was determined by the specific gravity bottle method, the liquid used being kerosene. The specific gravity of kerosene was also determined for use in the calculations. The specific gravity of these soils varies between 2·3 and 2·5.

TABLE XII

Name of soil	Specific gravity
Poona soil	2·27
Ranchi soil	2·40
Jhelum soil	2·35
Pusa soil	2·51

5. Specific heat

The specific heats of the same soils were determined by pouring hot water into a calorimeter containing a suspension of about forty grms. of soil in water

(known quantities of soil and water are mixed prior to the experiment and allowed to stand until the heat of wetting is dissipated and room temperature is attained by the mixture). The increase of temperature of the mixture was noted and the specific heat of the soil calculated in the usual manner. The table below gives the values of specific heats of the different soils. We shall have to use these values later in calculating the heat of wetting of the soils (next section).

TABLE XIII

Name of soil	Specific heat
Poona soil	0·22
Ranchi soil	0·20
Jhelum soil	0·23
Pusa soil	0·19

6. Heat of wetting

The heat of wetting with water was determined for soils from Poona, Ranchi, Jhelum and Pusa. Samples of these were heated to dryness at 100°C. and then allowed to cool in air-tight vessels. About thirty grm. of each soil* and water both initially at room temperature (25·9°C.) were mixed quickly in a small calorimeter kept inside a Dewar's flask, and the rise of temperature noted with a sensitive thermometer. The specific heat of the soil having been measured already, and the water equivalent of the calorimeter determined to start with, the heat of wetting per grm. of dry soil was calculated. The estimated heats of wetting are given below :—

TABLE XIV

Name of soil	Heat of wetting per gr. of soil in grm. calories (at 25·9° C.)
Poona	8·7
Ranchi	4·8
Jhelum	2·2
Pusa	1·2

To summarise the results of these experiments [Ramdas and Katti, 1935, 2] it is seen that (excepting of course the specific heat and true specific gravity) the following properties of soils vary in a similar manner (please also see Fig. 8 and the inset table in this connection) :—

(1) Diurnal variation of moisture,

(2) Water-holding capacity,

(3) Absorption of moisture in a definite time interval under steady laboratory conditions, and

(4) Heat of wetting.

* The determinations of absorption, specific gravity, specific heat and heat of wetting were all made with soils which had been passed through a 1 mm. sieve.

Section III

Laboratory determination of the desiccating power of different soils

We have seen that soils, when dry, absorb water vapour from the atmosphere and thus influence the distribution of water vapour in the air layers near the ground. To the meteorologist these results are interesting because the absorption of water vapour by the soil during the night and the evaporation of water from the soil during day time help to explain the observed diurnal variations in the pressure of water vapour. The fact that the diurnal variation of soil-moisture is confined to the first few inches of the soil also explains why a mulch helps to give a blanketing effect to the soil below and to conserve the moisture in the lower layers.*

It would be interesting also to study the efficiency of different soils as desiccating agents under steady conditions in the laboratory. The method adopted was to pass an air current (whose initial humidity was known) above dry soil and to note the decrease of humidity after passage.

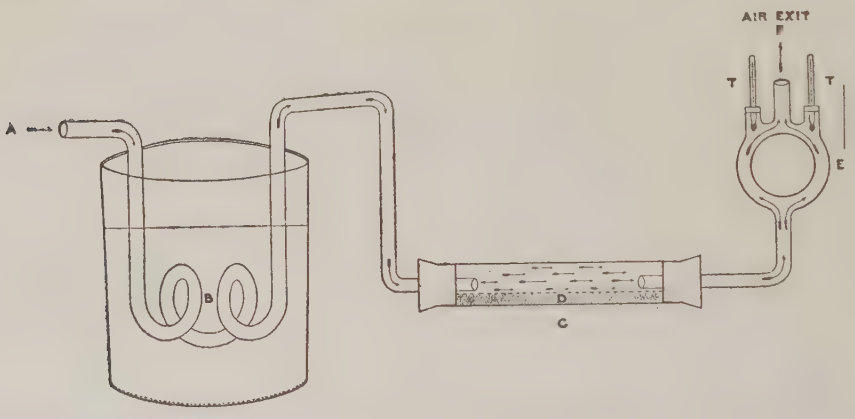


Fig. 9. Apparatus for the measurement of the desiccation of a current of air by different soils.

The experimental arrangement is shown in Fig. 9. The room air compressed by a blower passes into the spiral copper tube B and thence into the tube C which contains the dry soil. The copper spiral B is kept immersed in a water-bath at room temperature so as to maintain the initial conditions constant. This precaution is necessary because the blower gets warmer and warmer as it works and raises the temperature of the air current. After passing through the soil tube

*In this connection please see an interesting article on "The soil as a water reservoir" by T. Eden, *The Tea Quarterly, The Journal of the Tea Research Institute of Ceylon*, Vol. 8, part I, April 1935, p. 31.

C the desiccated air passes into the psychrometer E which has the dry-bulb thermometer T on one side and the wet-bulb thermometer T′ on the other. The thermometers T and T′ are screwed in position and may be removed easily for inspection or for wetting the muslin of the wet bulb thermometer. After passing by the bulbs of T and T′ the air finally emerges at F out into the room. To measure the initial humidity of the air current the tube C is removed and the air passed directly into E. In the initial experiments two psychrometric elements were used, one before and the other after the air current had passed through C, but it was found that the wet bulb of the first would then make the air current entering C more humid than the room air. During the course of the experiment readings of an Assmann Psychrometer were also taken at intervals in the room air outside the apparatus. The tube C was connected only after verifying that the pressure of water vapour in the air current as indicated by E was the same as that indicated by the Assmann Psychrometer. This was achieved by increasing the velocity of the air current in the apparatus until the depression of the wet bulb in E was maximum.

After ensuring that the tube psychrometer would function as efficiently as an Assmann Psychrometer and after recording the initial conditions, the tube C containing a known quantity of soil previously dried at 100°C. and spread uniformly along the tube, was inserted. Almost immediately the wet bulb T′ began to fall and within a few minutes attained a steady low value. The dry bulb T did not undergo any variation whatever as the heat of adsorption in the tube C was dissipated rapidly. The extent of the fall in T′ indicates the desiccating effect of the soil in C. The readings of T and T′ were recorded at short intervals of time until the soil in C was exhausted and T′ began to rise and ultimately attained the initial value again. The maximum fall of T′ as well as the time it took to regain the initial value differed from soil to soil, being large in the case of the black cotton soils and small in the case of soils of the alluvial type.

The velocity of the air current was measured during the experiment by noting the time taken for the displacement of a known volume of water. Also, the weight of soil in the tube C was noted both at the commencement and at the end of each experiment.

These experiments were performed with four soils, *viz.*, soils from Poona, Jalgaon, Bangalore and Lyallpur. For comparing the desiccating power of these soils with that of a standard substance the experiment was also repeated with a sample of " Sorbsil " supplied by the Cambridge Instrument Company. Tables XV to XIX give the full experimental details for the different substances in the order in which they are mentioned above.

Table XV

Poona soil

Time in minutes	Temperature and humidity of air current				Temperature and humidity of room air (with Assmann Psychrometer)				Other details
	Dry bulb T °C.	Wet bulb T' °C.	Humidity percentage	Vapour pressure in mm.	Dry bulb °C.	Wet bulb °C.	Humidity percentage	Vapour pressure in mm.	
0	23·3	14·5	37	8·0	23·8	14·6	36	7·9	
½	23·3	13·8	33	7·1	..	..	..	..	Weight of dry soil before passing air = 11·380 grms.
1	23·3	11·5	21	4·4	..	..	..	..	
1½	23·3	10·2	14	2·9	..	..	..	..	Weight of dry soil after passing air = 12·030 grms.
2	23·3	9·5	10	2·2	..	..	..	..	
3	23·3	9·0	8	1·6	..	..	..	..	Weight of water vapour absorbed by the soil . = 0·650 grm.
5	23·3	8·9	7	1·5	24·3	15·0	36	8·1	
8	23·3	8·9	7	1·5	..	..	..	..	
10	23·3	9·0	8	1·6	..	..	..	..	Velocity of air current . . = 43·8 c.c. per second.
14	23·2	9·3	9	1·8	..	..	..	..	
18	23·3	9·7	10	2·2	..	..	..	..	
24	23·4	10·4	14	3·0	..	..	..	..	Diameter of tube C = 1·3 cm.
30	23·4	10·9	16	3·5	..	..	..	..	Length of tube C = 1 metre.
35	23·8	11·4	18	3·9	..	..	..	..	Fraction of volume of C actually occupied by the soil = $\frac{1}{10}$
40	23·8	11·8	20	4·4	24·5	15·0	35	8·0	
50	24·0	12·0	23	5·2	..	..	..	..	
60	23·9	13·2	27	6·0	..	..	..	..	
70	24·3	13·8	29	6·6	..	..	..	..	
80	24·5	14·2	30	7·0	25·0	14·8	32	7·5	
90	24·8	14·5	31	7·2	25·2	14·4	29	6·9	

TABLE XVI

Jalgaon soil

Time in minutes	Temperature and humidity of air current				Temperature and humidity of room air (with Assmann Psychrometer)				Other details
	Dry bulb T °C.	Wet bulb T′ °C.	Humidity percentage	Vapour pressure in mm.	Dry bulb °C.	Wet bulb °C.	Humidity percentage	Vapour pressure in mm.	
0	25·3	15·1	32	7·8	25·2	15·2	33	8·0	Weight of dry soil before passing air = 11·710 grms.
1	25·3	12·5	18	4·5	..	..	..	..	
1½	25·3	11·2	12	2·9	..	..	..	..	Weight of dry soil after passing air = 12·280 grms.
2	25·3	10·7	10	2·3	..	..	..	..	
3	25·3	10·3	8	1·9	25·4	15·2	32	7·9	Weight of water vapour absorbed by the soil . = 0·570 grm.
4	25·3	10·2	7	1·8	..	..	..	..	
5	25·3	10·2	7	1·8	..	..	..	..	
6	25·2	10·3	8	1·9	..	..	..	..	Velocity of air current . . = 43·8 c.c. per second.
8	25·2	10·5	9	2·2	..	..	..	..	
10	25·2	10·6	10	2·3	..	..	..	..	
20	25·2	11·3	13	3·1	25·6	15·5	33	8·2	Diameter of tube C. = 1·3 cm.
25	25·2	11·6	14	3·4	..	..	..	..	Length of tube C . = 1 metre.
30	25·4	12·1	16	3·9	..	..	..	..	Fraction of volume of C actually occupied by the soil. = $\frac{1}{10}$
35	25·4	12·3	17	4·2	..	..	..	..	
40	25·4	12·9	20	4·9	..	..	..	..	
50	25·8	13·8	23	5·8	..	..	..	..	
60	25·8	14·4	27	6·6	..	..	..	..	
70	25·8	15·0	30	7·4	..	..	..	..	
80	26·2	15·5	31	7·9	26·0	15·4	31	7·8	

TABLE XVII

Bangalore soil

Time in minutes	Temperature and humidity of air current				Temperature and humidity of room air (with Assmann Psychrometer)				Other details
	Dry bulb T °C.	Wet bulb T′ °C.	Humidity percentage	Vapour pressure in mm.	Dry bulb °C.	Wet bulb °C.	Humidity percentage	Vapour pressure in mm.	
0	25·0	14·1	28	6·6	24·8	14·0	29	6·6	Weight of dry soil before passing air = 11·340 grms.
½	25·0	13·2	23	5·5	..	..	..	..	Weight of dry soil after passing air = 11·370 grms.
1	25·0	11·8	16	3·8	..	..	..	..	Weight of water vapour absorbed by the soil = 0·030 grm.
1½	25·0	11·6	15	3·5	..	..	..	..	
2	24·8	11·4	15	3·5	..	..	..	..	Velocity of air current = 43·8 c.c. per second.
3	24·8	11·8	17	3·9	..	..	..	..	
4	24·8	12·3	19	4·5	..	..	..	..	Diameter of tube C = 1·3 cm.
5	24·8	13·0	23	5·3	..	..	..	..	Length of tube C = 1 metre.
6	24·8	13·4	25	6·0	..	..	..	..	Fraction of volume of C actually occupied by the soil. = $\frac{1}{10}$
7	24·8	13·8	27	6·3	..	..	..	..	
8	24·8	14·0	28	6·6	..	..	..	..	
10	24·8	14·2	29	6·8	24·8	14·0	29	6·6	

Table XVIII

Lyallpur soil

Time in minutes	Temperature and humidity of air current				Temperature and humidity of room air (with Assmann Psychrometer)				Other details
	Dry bulb T °C.	Wet bulb T′ °C.	Humidity percentage	Vapour pressure in mm.	Dry bulb °C.	Wet bulb °C.	Humidity percentage	Vapour pressure in mm.	
0	25·4	14·0	26	6·3	25·5	14·3	27	6·6	Weight of dry soil before passing air = 11·400 grms.
½	25·4	13·0	21	5·0	..	..	..	..	Weight of dry soil after passing air = 11·427 grms.
1	25·4	12·0	16	3·8	..	..	..	..	
1½	25·4	11·7	14	3·5	..	..	..	..	Weight of water vapour absorbed by the soil . = 0·027 grm.
2	25·4	12·0	16	3·8	..	..	..	..	
3	25·4	12·3	17	4·2	..	..	..	..	Velocity of air current . . = 43·8 c.c. per second.
4	25·4	12·8	20	4·8	..	..	..	..	
5	25·4	13·3	22	5·4	..	..	..	..	Diameter of tube C = 1·3 cm.
6	25·4	13·7	24	5·9	..	..	..	..	Length of tube C = 1 metre.
7	25·4	14·0	26	6·3	..	..	..	..	Fraction of volume of C actually occupied by the soil. = $\frac{1}{10}$
8	25·4	14·1	26	6·4	25·4	14·2	27	6·5	

Table XIX

Sorbsil

Time	Temperature and humidity of air current				Temperature and humidity of room air				Other details
	Dry bulb °C.	Wet bulb °C.	Humidity percentage	Vapour pressure in mm.	Dry bulb °C.	Wet bulb °C.	Humidity percentage	Vapour pressure in mm.	
0	30·5	17·7	27	8·8	30·5	17·6	26	8·6	
½ min.	30·4	15·5	17	5·7	..	..	..	..	Weight of dry sorbsil before passing air . . =12·000 grms.
1 min.	30·3	14·3	13	4·2	..	..	..	..	
2 min.	30·3	13·5	10	3·2	..	..	..	..	Weight of sorbsil after passing air =13·430 grms.
3 min.	30·3	13·3	9	2·9	..	..	..	..	
5 min.	30·3	13·6	10	3·3	..	..	..	..	Weight of water vapour absorbed by sorbsil . =1·430 grms.
8 min.	30·3	13·7	11	3·5	..	..	..	..	
12 min.	30·4	14·0	12	3·8	..	..	..	..	Velocity of air current . . =43·8 c.c. per second.
20 min.	30·5	14·2	12	4·0	..	..	..	..	
26 min.	30·9	14·5	12	4·2	31·1	17·5	24	8·2	Diameter of tube C =1·3 cm.
30 min.	30·7	14·7	13	4·4	..	..	..	..	Length of tube C =1 metre.
36 min.	30·5	15·0	15	5·0	30·7	17·6	26	8·5	Fraction of volume of C actually occupied by sorbsil $=\frac{4}{25}$
42 min.	30·6	15·1	15	5·1	..	..	..	..	
48 min.	30·8	15·3	16	5·4	31·1	17·5	24	8·2	

1 hour 4 min.	31·3	15·6	16	5·4	..	..	..	..
1 hour 16 min.	30·7	15·8	18	6·0	..	..	..	..
1 hour 33 min.	31·0	16·2	19	6·4	..	..	..	..
1 hour 43 min.	31·0	16·3	19	6·5	..	..	..	..
1 hour 53 min.	31·1	16·5	20	6·8	31·5	17·3	22	7·7
2 hours	31·2	16·7	21	7·0	..	..	..	..
2 hours 10 min.	31·5	16·8	21	7·3	..	..	..	..
2 hours 20 min.	31·2	16·9	21	7·3	31·5	17·0	21	7·3
2 hours 30 min.	31·2	16·9	21	7·3	..	..	..	..
2 hours 40 min.	31·3	16·9	21	7·3	..	..	..	..
2 hours 50 min.	31·3	16·9	21	7·3	31·5	17·0	21	7·3

The velocity of the air current was adjusted so as to allow 43·8 c.c. of air per second to pass through the apparatus. After passage above the soil exposed in the drying tube C, the wet bulb temperature rapidly fell in the first few minutes and slowly rose again. Each experiment was concluded as soon as the air current ceased to be desiccated, *i.e.*, as soon as the soil had got exhausted and no longer absorbed any moisture from the air current. When this stage was reached the humidity of the air current was practically identical with that of the room air outside the apparatus.

In the case of Poona and Jalgaon soils and of sorbsil, the time taken for completely exhausting the desiccating power was of the order of 80 to 150 minutes. During the interval the room air sometimes underwent a slight change in its moisture content, but such change was invariably small when compared to the changes of vapour pressure and humidity experienced by the air current on passing through the soil in the tube C.

A decrease in the vapour pressure by 1 mm. of mercury corresponds to a loss of 10^{-6} grm. of water vapour per cubic centimetre or to one grm. of water vapour per cubic metre of air. If we plot the values of vapour pressure against time we shall be able to calculate from the area of the curve and the velocity of the air current in cubic centimetres per second, the total mass of water vapour extracted from the air current by the soil. For example, if A is the area of the curve when the vapour pressure is expressed in mm. of mercury and time in minutes and if V is the volume of air in c.c. entering the tube C per second, the mass of water vapour absorbed in grms. is given by :

$$A \times 60 \times V \times 10^{-6}.$$

TABLE XX

Name of soil	Wet bulb temperature in °C.			Humidity percentage			Vapour pressure (mm. of Hg.)			Time taken for attaining minimum value in minutes (t_1)	Time taken for completely exhausting the drying power of the soil in minutes (t_2)	Moisture gained by soil			Velocity of air current in cubic centimetres per second	Total volume in cubic metres of air passed over soil during the experiment ($V \times t_2$)	Mass of water lost by the air (actual dehydration) (grm.)	Amount of dehydration of air expressed in grammes per cubic metre	Mass of soil required to produce the observed dehydration in one cubic metre of air (grms.)
	Initial value	Minimum value	Maximum decrease caused by soil	Initial value	Minimum value	Maximum decrease caused by soil	Initial value	Minimum value	Maximum decrease caused by soil			Dry weight (M) of soil in grammes	Mass of water (m) absorbed in grammes	Expressed as percentage of dry weight of soil					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Poona . . .	14·5	8·9	5·6	37	7	30	8·0	1·5	6·5	6·0	90	11·380	0·650	5·7	43·8	·236	0·730	3·09	48·12
Jalgaon . .	15·1	10·2	4·9	32	7	25	7·8	1·8	6·0	5·0	80	11·710	0·570	4·9	43·8	·210	0·620	2·95	55·71
Bangalore . .	14·1	11·4	2·7	28	15	13	6·6	3·5	3·1	2·0	10	11·370	0·030	0·3	43·8	·026	0·030	1·14	379·00
Lyallpur . .	14·0	11·7	2·3	26	14	12	6·3	3·5	2·8	1·5	8	11·400	0·027	0·2	43·8	·021	0·027	1·29	542·86
Sorbsil . . .	17·7	13·3	4·4	27	9	18	8·8	2·9	5·9	3·0	150	12·00	1·430	11·7	43·8	·394	1·740	4·41	30·44

This value can be compared with the actual increase in weight of the soil at the end of the experiment.

The vapour pressure-time curves are shown in Fig. 10. Sorbsil is an efficient absorber, and retains its power to absorb for the longest time. Next in order come the soils from Poona, Jalgaon, Bangalore and Lyallpur, respectively. The last two cause only a small depression in the wet-bulb temperature and the vapour pressure, and, even so, get exhausted within ten minutes. In all cases the dehydration of the air current is rapid and the vapour pressure attains its minimum value within a few minutes after the commencement of the experiment ; thereafter the vapour pressure slowly increases and becomes equal to that of the air outside.

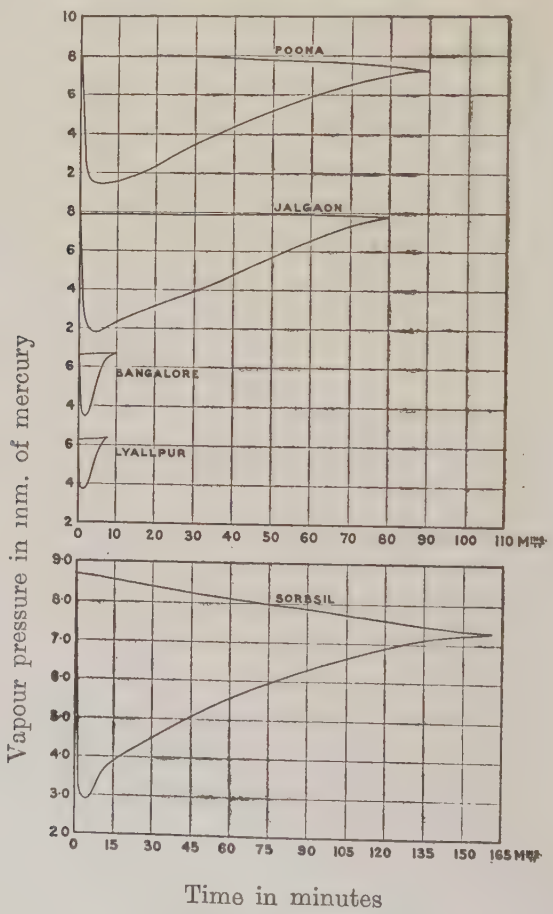


FIG. 10. Curves showing the variation of vapour pressure with time in the case of different soils and sorbsil; the straight lines at the top of each curve shows the vapour pressure in the room air outside the apparatus.

The results which may be deduced from Tables XV to XIX and from the curves in Fig. 10 are summarised in Table XX where, for facility of reference, the columns are numbered serially. Columns (2) to (10) give the initial and minimum values as well as the differences between these values in the case of the wet-bulb temperature, humidity percentage and the pressure of water vapour, in the experiments with the four soils and with sorbsil. Column (11) gives t_1 the time taken for attaining the minimum value and column (12) gives t_2 the total time taken for completely exhausting the absorbing power of each of the above substances. Column (13) gives the actual mass M of the substances used in the different experiments; this is usually between eleven and twelve grammes. Column (14) gives the mass of water vapour m absorbed in t_2 minutes. Column (15) gives the value of $\frac{m}{M} \times 100$. Column (16) gives the velocity V, of the air current which was adjusted to be 43·8 c.c. per second in all the experiments. Column (17) indicates the total volume of air which passed through the tube C in t_2 minutes. This volume is expressed in cubic metres. The next column (18) gives the mass of water lost by the air as calculated from the curves in Fig. 10 ($A \times 60 \times V \times 10^{-6}$). These values may be compared with the values of m in column (14). There is fairly good agreement in the values. The mass of water lost by the air can also be expressed in grms. per cubic metre (column 19). In the last column (20) is given the mass of soil required to desiccate one cubic metre of air to the extent indicated in column (19). From column (20) we note that with about fifty grms. of dry Poona soil we can remove about three grms. of water from one cubic metre of damp air. These figures do suggest that the black cotton soils may be used with profit for keeping the air in an enclosed space dry. The cost involved would be negligible when compared to that of common drying agents like sulphuric acid, calcium chloride, phosphorous pentoxide, etc. Further experiments to make practical use of the above results are in contemplation.

The investigations described in the preceding sections are intended to provide a general survey of this subject. The soils have been studied more or less as they exist in nature and there is ample scope for further investigations with the various constituents of each soil which may be separated by mechanical as well as chemical analysis. It would also be interesting to carry on the investigations on the moisture-variation index with each soil in its own natural environment, *e.g.*, Pusa soil at Pusa, Lyallpur soil at Lyallpur and so on.

In conclusion the authors desire to express their best thanks to the Director-General of Observatories for facilities given at the laboratories of the Meteorological Office at Poona. This investigation was made in the Agricultural Meteorology Section (India Meteorological Department) financed by the Imperial Council of Agricultural Research.

REFERENCES

Ramdas, L. A. and Katti, M. S. (1934, 1). *Ind. J. Agric. Sci.* **4**, 923-37.

——————————— (1934, 2). *Current Sci.* **3**, 24.

——————————— (1935, 1). *Current Sci.* **3**, 612-13.

——————————— (1935, 2). *Current Sci.* **4**, 419.

STUDIES ON SOIL-MOISTURE

I. MOVEMENT OF SOIL-MOISTURE UNDER FIELD CONDITIONS

BY

M. CARBERY, D.S.O., M.C., M.A., B.Sc.,
Assistant Director of Agriculture, Bengal

AND

M. N. CHAKLADAR, M.Sc.,
Physical Chemist

(Received for publication on 20th November 1935)

(With eight text-figures)

The relation between water and a complex body like soil is one of the most complicated problems in soil physics. These complications multiply in the field where the conditions are daily changing and where the meteorological conditions, over which no control is possible, influence the movement of soil-moisture to a very great extent.

Apart from the external factors the inherent characteristics of the soil are so very widely varying from field to field and from year to year in the same field that any mathematical explanation will be far from satisfactory. Notwithstanding this, the problem is so very interesting and important both from the theoretical and practical point of view that much attention is being paid by soil scientists from all quarters.

Briggs [1907] considered soil as a bundle of capillary tubes and introduced the capillary hypothesis to explain the upward and horizontal flow of water inside the soil. King [1889], Hall [1904], Cameron [1911], McGee, Leake [1905] and others hold that sub-soil water rises up to supply the requirements of the crop, the range varying from 200 ft. to a minimum of 10 ft.

Keen [1918] has shown that in the case of an ideal soil, sub-soil water may rise up to 150 ft. but the process is extremely slow. But what is true of an ideal soil is never so for an ordinary soil specially under field conditions.

But none could assert with any degree of certainty the height to which water can rise by capillarity. On the other hand, more recent workers—Alway, Tulaikow, Burr 1914] are of opinion that sub-soil water is never available to the crop,

unless the roots themselves travel down to avail the water accumulated underneath.

The mode of capillary rise of sub-soil water in nature is a controversial point. Leather [1908] assumes that capillarity starts from the surface and gradually goes down as evaporation proceeds during the dry months and extends only to a limited depth. While Alway and Mcdole [1917] point out that sub-soil water rises up but the process is so very slow that it is doubtful whether this moisture will be able to reach the roots of annuals in the course of a growing season. Sen [1930] has shown that the upward movement of water starts from the surface and does not extend beyond 3 ft. The authors also hold the same opinion with Leather and Sen [*loc. cit.*] and show that the upward movement starts from the surface and seldom extends beyond 21 in. in the case of the Dacca Farm Soil.

Although Bengal gets sufficient rains during the monsoon, the highland tract dries up hopelessly during the dry season rendering winter cultivation quite disappointing. The investigation has been undertaken with the object of finding out ways and means of retaining optimum moisture specially for *rabi* cultivation.

Before making any attempt at retaining the soil-moisture it was worth-while studying the movement of soil-moisture in Bengal where the water-table rises up within 10 ft. from the surface and often much less than that during the monsoon and where the dry season does not extend over six months.

The first attempt at making a systematic study of the movement of soil water was to find out the moisture-content of the soil *in situ* at different depths during the dry season. Soil was bored down to a depth of 30 in. taking 3 in. at a time and moisture estimated for each depth. In order to facilitate the comparison of the moisture-content at various depths at different periods of the dry season, the data obtained in these experiments may be evaluated by graphical interpolation. The moisture distribution curves are all more or less continuous and show no abrupt changes of direction. The nature of the curves suggests an empirical exponential equation of the type

$$Y = Ao\ (1 - b\, e^{-a\, x})$$

where Ao is the maximum moisture-content, Y is the moisture-content at the depth x and b and a are constants. So that, when

$$x = 0\ ,$$

$$Y = Ao\,(1 - b)$$

and when $x = \infty$ (infinity) *i.e.* at great depth, $Y = Ao$.

The maximum value of the moisture has been obtained from the actual values and the curves have been fitted by method of least square (Figs. 4 & 5).

The agreement in the observed and the calculated values is fairly good. Thus beyond a certain depth, the moisture remains constant whatever the depth might be.

Water is held by the soil in the interstitial spaces due to surface tension. The essential condition for any mathematical interpretation of the mode of distribution of a given amount of moisture is that the curvature at all air-water interfaces is the same. The curvature increases or decreases according as the moisture-content of the soil becomes low or high. If we assume that the soil particles are uniform in diameter and if the packing is uniform throughout, the curvature shall be the same at all points, that is, the water film surrounding each soil particle will be of uniform thickness. At saturation, the air-water boundary is plain and the curvature increases as the moisture decreases and hence proportionately a greater energy is necessary to remove the water from the soil. Experimental results lend support to the assumption. It has been found in this experiment and by other workers particularly by Leather that the loss of moisture per unit of time depends on the quantity of moisture present in the soil. As the water escapes from the surface, the curvature of the air-water interfaces increases so that the surface is always in a state of tension hence it sucks water from beneath in order to reduce the curvature to a minimum and so does the next layer and so on. Thus the capillarity starts from the surface. The curvature of the air-water interfaces gradually decreases with the depth resulting in decrease of suction-pressure and ultimately it becomes so small that the water it pulls up from the next layer is negligibly small. In other words the capillarity does not extend beyond a certain depth for all practical purposes. Though the moisture-content remains constant beyond 21 in., it is unfair to assume that there is no movement of water at all there. Movement of water actually takes place but the region is in dynamic equilibrium. This region may be called the "Equilibrium moisture zone". It will be found from Table II that the evaporation coefficient assumes a negligible value at the equilibrium moisture zone. This is due to the fact that the soil there is saturated with water up to its field capacity so that the soil atmosphere above it contains more water-vapour than the upper layer. Hence the evaporation of water from the soil at that layer is negligibly small. Any loss, however small, from this layer is compensated by the capillary rise from the layer below it. Thus a dynamic equilibrium is established.

During the dry months, moisture does leave soil and the loss depends upon the meteorological conditions, *i.e.*, temperature, humidity, velocity of wind, etc., but as it has not been possible to have these data, the following deductions have been made as if the evaporation takes place under uniform temperature and humid conditions.

Thus if V be the water-content of the soil at any time t, then

$$-\frac{dv}{dt} = Ka \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(i)}$$

where 'a' is the fraction of the surface covered with water-film and K is a constant which varies with the depth. Since the spheres are all uniform, they will have uniform moisture film surrounding them, that is, the thickness of the film will be

the same everywhere. Therefore 'a' is proportional to V. Substituting V for 'a' we have,

$$-\frac{dv}{dt} = K_1 V \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(ii)}$$

i.e., the rate of loss of moisture $\frac{dv}{dt}$ is given as a product of V, the moisture-content and a constant K_1 which varies from layer to layer.

$$\frac{d \log V}{dt} = K_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(iii)}$$

Now V, the volume of the water actually found in the soil, is not all mobile, a part H (the residual moisture in the air-dry soil) cannot escape from the soil in the field under any circumstances hence while considering V, H must be deducted from it.

Thus substituting $(V—H)$ for V we have

$$\frac{d \log (V—H)}{dt} = K_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(iv)}$$

$$d \log (V—H) = K_1 \, dt$$

$$\log (V—H) = K_1 t + K_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(v)}$$

At a depth when K_1 assumes a negligible value,

$$\log (V—H) = K_2 = \text{constant.}$$

The above expression is a true measure of the moisture-content of the soil at any depth upto the limit of the experiment. The expression V involves two constants, K_1 and K_2 which require further discussion. The constant K_2 is evidently an arbitrary constant while K_1 is the coefficient of evaporation. It has already been stated that the moisture-content of the soil increases with the depth and assumes a constant value beyond 21 in. Apparently, the effect of evaporation beyond 21 in. is negligibly small. Hence, theoretically, K_1 should gradually decrease up to a certain depth, beyond which it becomes zero or less than any assignable quantity, while the arbitrary constant K_2 should gradually increase to a maximum constant value.

Experimental

Three sub-plots (18 ft. × 10 ft.) were selected from the experimental plot of the Dacca Farm high land area. The plots were ploughed, weeded off, laddered and kept undisturbed for the whole period of dry season. Before starting the experiment, eight points were marked off in each sub-plot.

Soil samples were collected from the plots up to a depth of 30 in. taking 3 in. of soil at a time. Each boring was thoroughly mixed up in a covered aluminium pot and about 30 40 grms. of soil were taken in a stoppered weighing bottle and weighed in the field. These samples were collected periodically at an interval of

three to four weeks, care being taken that the distance between the respective borings was never less than 3 ft. The samples were then taken to the Laboratory where it was dried at 105°C.—110°C., cooled in desiccator, weighed and moisture calculated on dry basis.

TABLE I

Total moisture in soil in situ *at varying depths—Dacca Farm*

Plot No. 12

Depth in inches	Moisture percentage 7th December 1932	Moisture percentage 28th December 1932	Moisture percentage 20th January 1933	Moisture percentage 17th February 1933	Moisture percentage 23rd March 1933	Moisture percentage 5th April 1933
0—3 . .	15·69	12·24	10·38	6·48	4·83	2·89
3—6 . .	17·25	17·84	13·55	11·90	10·56	7·63
6—9 . .	18·25	16·75	18·35	13·80	12·48	10·08
9—12 . .	20·31	18·88	20·21	17·00	16·28	12·42
12—15 . .	20·68	20.79	21·39	19·01	16·37	15·21
15—18 . .	22·38	22·08	22·26	20·00*	18·68	19·88
18—21 . .	22·90*	24·36	22·81	22·31	22·55	22·12
21—24 . .	23·42	24·94	24·50*	21·80	22·06	..
24—27 . .	23·69	24·04	25·30	22·22	22·24	..
27—30 . .	23·84	24·00	25·51	22·45	21·24	..

* The figures marked with asterisks have been obtained by interpolation.

Total moisture in soil in situ *at varying depths—Dacca Farm*

Plot No. 23

Depth in inches	Moisture percentage 28th December 1932	Moisture percentage 17th January 1933	Moisture percentage 17th February 1933	Moisture percentage 9th March 1933	Moisture percentage 5th April 1933
0—3 . .	11·31	8·82	6·80	5·93	4·44
3—6 . .	15·01	13·63	12·62	11·83	10·50
6—9 . .	18·32	15·64	15·20	15·73	14·66
9—12 . .	19·44	19·66	18·10	18·24	17·25
12—15 . .	22·88	22·18	21·23	19·87	19·38
15—18 . .	24·28	23·39	23·15	22·94	21·06
18—21 . .	24·23	24·36	23·33	23·10	22·00
21—24 . .	24·82	23·91	23·99	23·00*	23·24
24—27 . .	24·50	24·32	23·73	22·95	23·55
27—30 . .	23·48	23·41	23·17	23·25	22·35

* The figures marked with asterisks have been obtained by interpolation.

Total moisture in soil in situ *at varying depths—Dacca Farm*

Plot No. 30

Depth in inches	Moisture percentage 8th December 1932	Moisture percentage 7th January 1933	Moisture percentage 3rd February 1933	Moisture percentage 4th March 1933	Moisture percentage 23rd March 1933	Moisture percentage 8th April 1933
0—3 . .	15·60	9·21	8·48	5·81	4·06	3.38
3—6 . .	17·65	11·60	12·66	10·12	11·17	8·37
6—9 . .	18·51	14·28	12·30	12·85	13·08	12·59
9—12 . .	22·40	18·43	20·22	17·62	16·84	18·71
12—15 . .	24·67	19·52	21·09	21·40	20·56	21·21
15—18 . .	25·09	19·28	21·93	22·09	21·22	22·80
18—21 . .	25·69	20·72	22·66	20·17	22·46	22·57
21—24 . .	25·69	22·42	23·00	23·51	21·74	22·30
24—27 . .	24·44	21·68	22·52	23·61	21·47	22·54
27—30 . .	24·54	22·14	23·12	23·61	22·22	22·78

The surface layer being directly influenced by the sun, the wind and other meteorological changes dries up very quickly and as such suffers maximum loss. This loss of moisture decreases with the depth and then becomes constant (Figs. 1, 2 and 3). These curves are similar to those of Greene [1928]. The graphs bring out some interesting features. In the first place the graphs are all smooth and tend to converge to a depth of about 21 in. then diverge almost parallel to the axis of depth showing that the soil profile is uniform up to the depth considered and beyond that depth the moisture-content remains constant. The steepest curve is obtained at the end of the dry season while the flattest at the beginning, thus indicating that the effect of evaporation is perceptible only up to a depth of a few inches.

Plot No. 12.

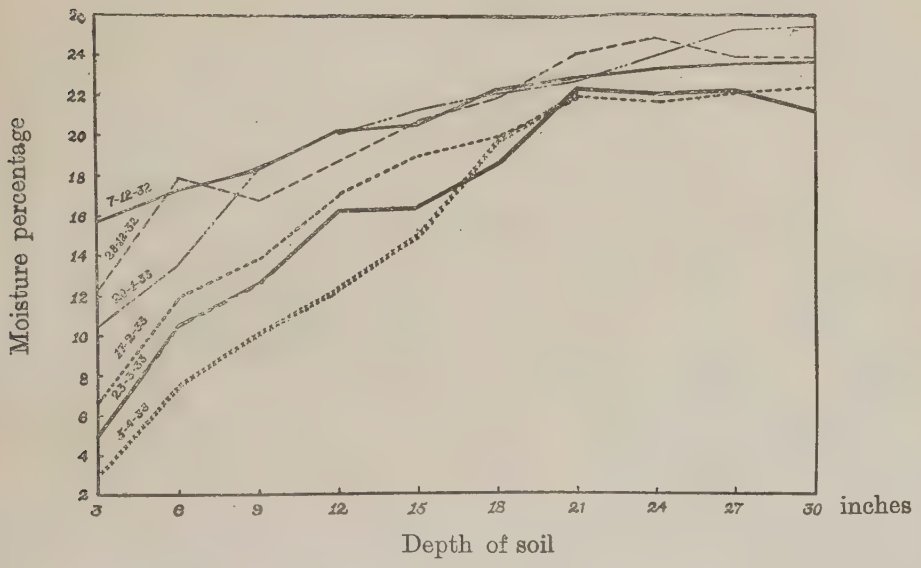


Fig. 1.

Plot No. 23.

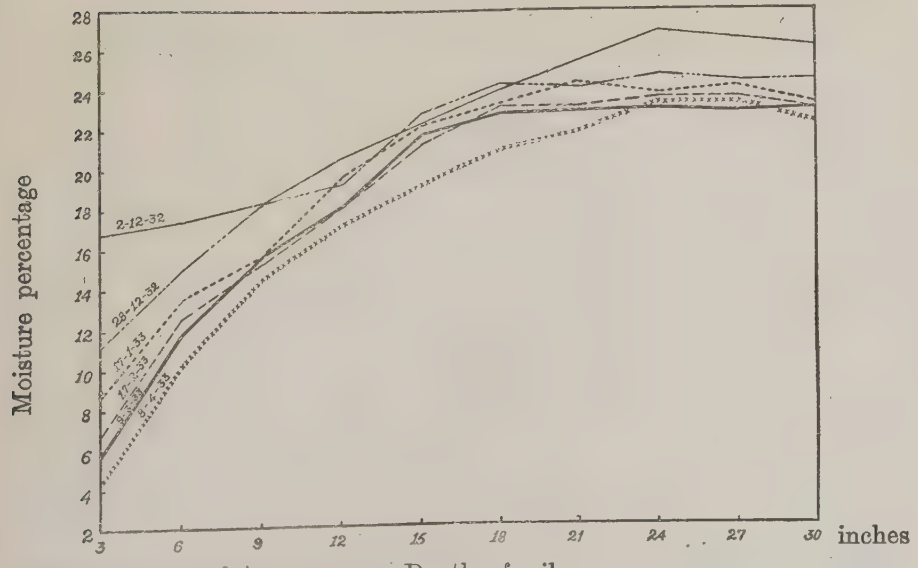


Fig. 2.

Plot No. 30.

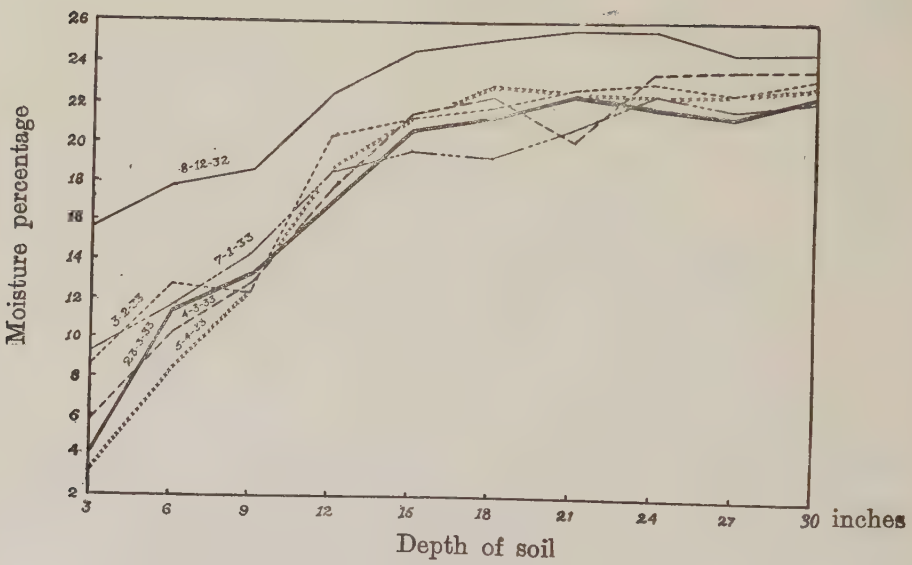
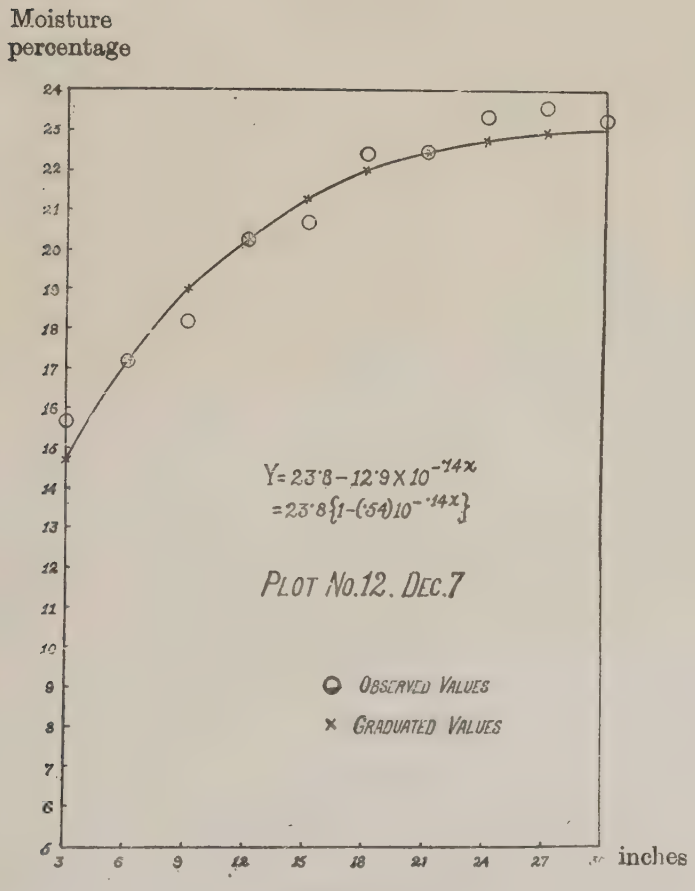


Fig. 3.

The above curves may be represented by the exponential equation already discussed—two curves are shown here (Figs. 4 and 5).

Curve No. 1.



Depth of soil

Fig. 4.

Curve No. 2.

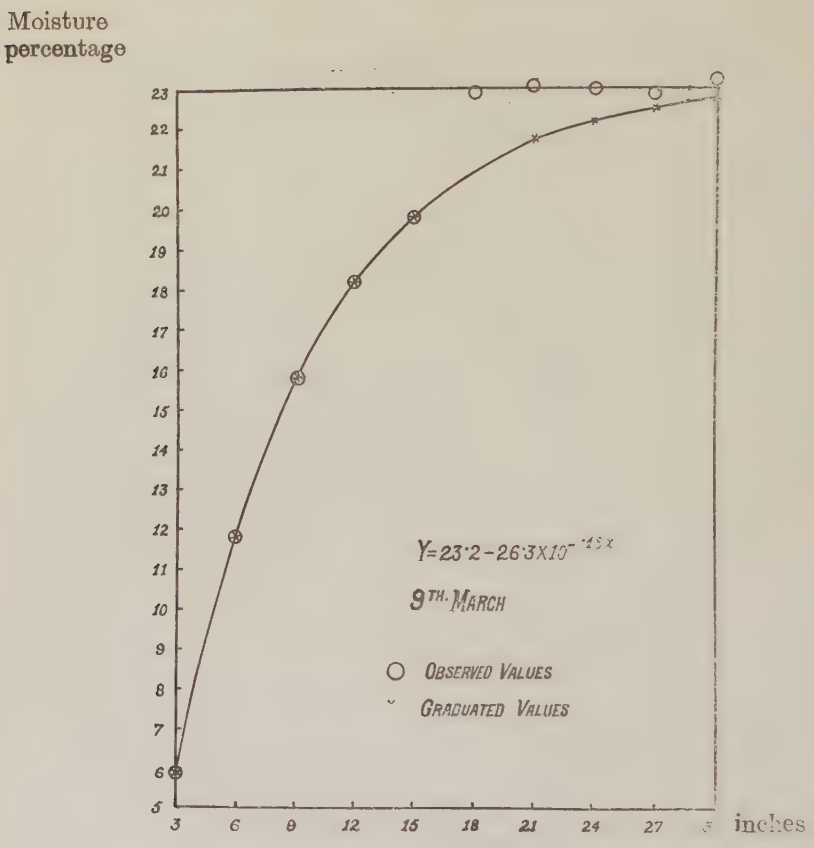


Fig. 5.

The above equation is purely an empirical one and has got no theoretical bearing. Since the soil profiles are scarcely uniform the moisture content will depend upon the physical nature of the soil.

An inspection of the figures in Table I, shows that evaporation proceeds in every layer of the soil *in situ* during the dry months resulting in the decrease of the moisture per cent in all the layers up to the "Equilibrium-moisture-zone." The data can be correctly fitted up into the evaporation equation (v). On plotting log $(V—H)$ against t (t being recorded in days), it is found that all the points lie about a straight line (Figs. 6, 7 and 8).

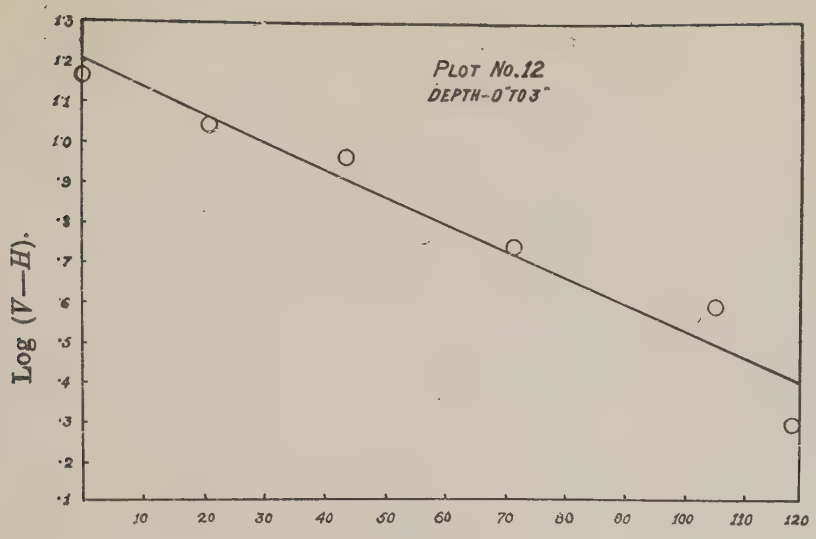

PLOT No.12
DEPTH-0"TO3"
Log (V—H).
·1
·2
·3
·4
·5
·6
·7
·8
·9
1·0
1·1
1·2
1·3
10
20
30
40
50
60
70
80
90
100
110
120
t in days

Fig. 6.

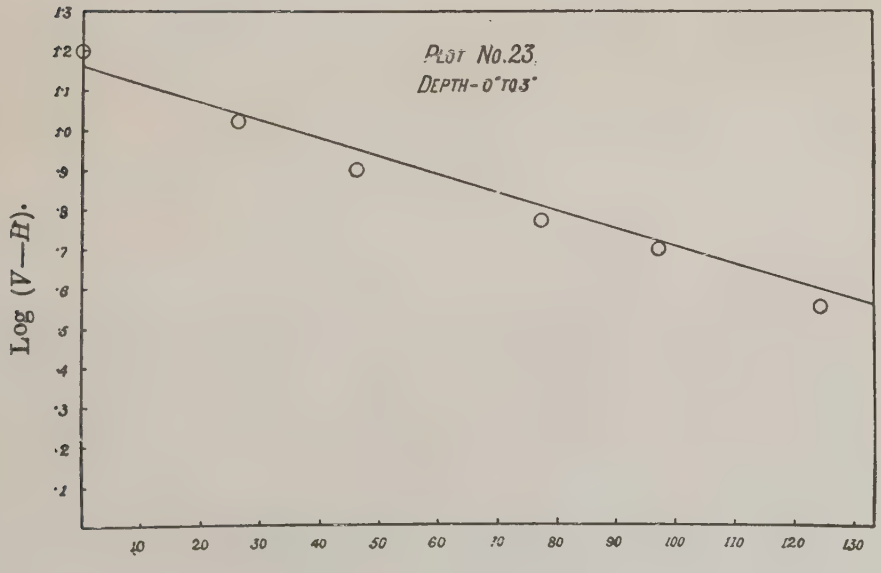

PLOT No.23.
DEPTH-0"TO3"
Log (V—H).
·1
·2
·3
·4
·5
·6
·7
·8
·9
1·0
1·1
1·2
1·3
10
20
30
40
50
60
70
80
90
100
110
120
130
t in days

Fig. 7.

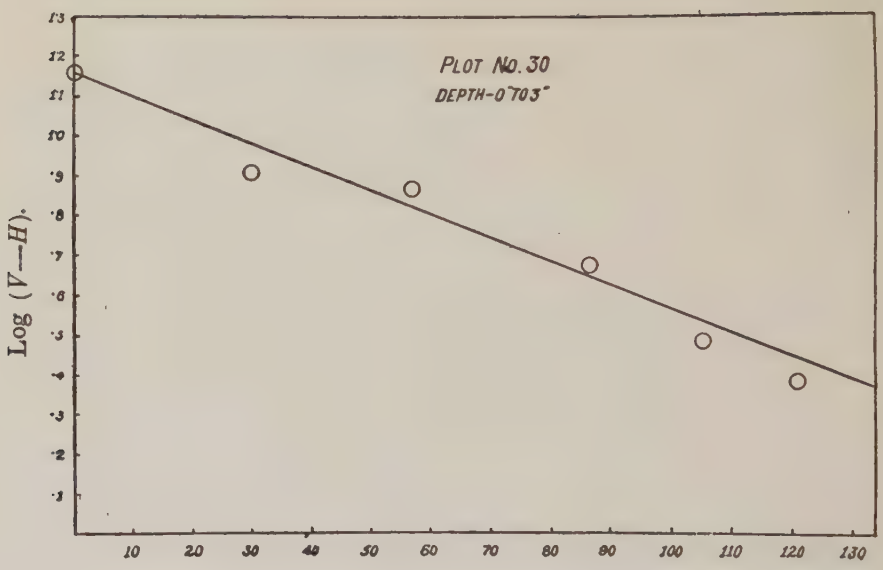


Fig. 8.

These graphs are all of different slopes which decrease as the depth increases until at the " Equilibrium-moisture-zone ", they become practically parallel to the axis of time which lends further support to the fact that the moisture-content remains practically constant beyond a certain depth, *i.e.* beyond the " Equilibrium-moisture-zone " and further that the capillarity does not extend beyond a certain depth. The linear equation (v) being the true measure of the moisture-content of the soil, the value of the constants may be of some interest. They have been worked out from the experimental data. A glance at Table II will show that the evaporation constant K_1 decreases with the depth and reaches zero at infinite depth but its value beyond 21 in. is negligibly small and may be taken to be zero for all practical purposes and log K_2 approaches its maximum constant value.

TABLE II

Table for the constants

	$-K_1$	K_2
Plot No. 12.		
0″—3″	0·006743	1·2110
3″—6″	0·003091	1·2453
6″—9″	0·001511	1·2141
9″—12″	0·001746	1·2983
12″—15″	0·001421	1·3116
15″—18″	0·0007803	1·3281
18″—21″	0·001268	1·3299
21″—24″	0·001044	1·3794
24″—27″	0·0005704	1·35702
27″—30″	0·0006016	1·3583
Plot No. 23		
	$-K_1$	K_2
0″—3″	0·005059	1·1670
3″—6″	0·001625	1·1469
6″—9″	0·0008029	1·2071
9″—12″	0·0006208	1·2564
12″—15″	0·0008666	1·3236
15″—18″	0·0006420	1·3539
18″—21″	0·0004882	1·3501
21″—24″	0·0003175	1·3519
24″—27″	0·000255	1·3481
27″—30″	0·000135	1·3270
Plot No. 30		
	$-K_1$	K_2
0″—3″	0·006179	1·1656
3″—6″	0·002264	1·1716
6″—9″	0·000985	1·1664
9″—12″	0·00077	1·2889
12″—15″	0·0003574	1·3123
15″—18″	0·0001398	1·3164
18″—21″	0·000351	1·3275
21″—24″	0·0004539	1·3558
24″—27″	0·0002208	1·3277
27″—30″	0·0002037	1·3302

It will be observed from the above that certain discretion had to be applied in representing the moisture-content by the regression equation (v), hence it is worthwhile to submit the values of the constants to a more rigorous test. The values of K_1 and $\log K_2$ in the table have been calculated from equation (v). The high correlation coefficient ($r = 0{\cdot}97$) between the observed and the calculated

values leaves no doubt as to the validity of the deductions applied under field conditions. The slight discrepancy in the result is not surprising in view of the various sources of error involved in the experiment and numerous assumptions made in the deduction.

The following table shows the observed and the calculated values of log (V—H) of the 1st layer (0″-3″).

TABLE III

Plot No. 12	
log (V—H) observed	Log (V—H) calculated
1·1690	1·2110
1·0554	1·0694
0·9754	0·9144
0·7442	0·7256
0·5910	0·4963
0·2920	0·4086
Plot No. 30	
log (V—H) observed	Log (V—H) calculated
1·1664	1·1656
0·9190	0·9802
0·8779	0·8135
0·6842	0·6342
0·4913	0·5166
0·3890	0·4179
Plot No. 23	
log (V—H) observed	Log (V—H) calculated
1·2041	1·2110
1·0162	1·0355
0·8940	0·9343
0·7686	0·7775
0·6989	0·6763
0·5453	0·5397

Similar agreements were obtained for other depths also.

EFFECT OF RAINFALL

If there be any rainfall during the tenure of the experiment, the entire course of moisture movement will be disturbed and as such any deduction be erroneous. If the rainfall be sufficiently heavy as to accumulate a good deal of water on the surface then the depth to which this water will penetrate by percolation will depend upon the equilibrium-moisture holding capacity of the soil which in the case of the Dacca Farm soil is about twenty-three per cent, so the amount of water that will be absorbed by the soil will be the difference between the equilibrium-moisture holding capacity and the actual moisture-content of the soil.

But if the rainfall be not sufficient to saturate all the soil above the Equilibrium-moisture-zone so as to raise it to the equilibrium-moisture-content then the

water will travel only to a limited depth thus increasing the moisture content of the upper layers. The surface being more susceptible to evaporation, dries up quickly, scarcely leaving any opportunity to detect the increase of moisture, unless the observation is made shortly after, while the intermediate layers show a definite increase in the moisture per cent.

Though the rainfall was very insignificant during the 1st stage of experiment, the difference between the successive periods indicates clearly the departure from the normal process of drying.

TABLE IV

Moisture after rainfall

Depth	Plot No. 23 Moisture percentage 25th May	Plot No. 12 Moisture percentage 15th May	Plot No. 30 Moisture percentage 26th May
0″—3″	18·35	27·07	15·45
3″—6″	18·35	23·25	18·95
6″—9″	14·87	22·20	19·05
9″—12″	16·05	21·80	21·55
12″—15″	20·15	21·88	22·42
15″—18″	20·65	24·51	21·42
18″—21″	22·58	18·96	24·50
21″—24″	26·15	21·81	27·93
24″—27″	26·45	22·28	23·40
27″—30″	24·80	22·30	22·65

Rainfall	In.	*Rainfall*	In.
November 1932	0	May 1933—	
December 1932	0	1st	0·44
January 1933—		5th	0·05
22nd	0·05	6th	1·06
25th	0·03	9th	1·22
February 1933—		10th	0·02
13th	0·8	11th	0·04
19th	0·11	12th	0·40
		18th	1·28
		22nd	0·35
March 1933	0	23rd	0·57
April 1933—		25th	0·47
14th	2·70	30th	1·80
15th	0·45		
16th	1·32		
17th	1·28		
18th	..		
19th	0·6		
20th	0·36		
23rd	2·65		
Total	9·36	Total	7·70

It will be seen from the above tables that there had been abundant rainfall during the months of April and May to accumulate a good deal of water so as to allow percolation down to the lower layers or even to the water-table below. Table IV shows that though the rainfall was heavy, the moisture-content of the soil in any layer never exceeded twenty-three per cent which is the Equilibrium-moisture holding capacity of the soil under investigation. Hence it follows that a portion of the rain water was used up in raising the soil of the upper layers to its equilibrium-moisture-content and the excess water percolated down to the lower layers.

But as a matter of fact winter rainfall in Bengal is scarcely sufficient to moisten the soil to any depth hence the considerations can seldom be useful. This is, however, of importance where irrigation water is concerned. The supply of too much water for irrigation purposes is simply to run it to waste.

In conclusion, the authors take the opportunity of expressing their indebtedness to the Imperial Council of Agricultural Research for the financial grant towards the cost of the investigation.

Our acknowledgments are due to Messrs. K. McLean, B.Sc., Director of Agriculture, Bengal and to Gostabehari Pal, M.Sc., Agricultural Chemist, Bengal, for the kind interest they took in the investigation.

Summary

1. The condition of soil-moisture *in situ* at varying depths have been studied in the Dacca Farm (highland) during the dry season. The loss of soil-moisture is greatest and very rapid in the 1st three inches then gradually decreases up to a depth of 18 in. Beyond 18 in. there is an "Equilibrium-moisture-zone" which remains at the same moisture-content up to the end of the dry season. The moisture-content at this zone is about twenty-three per cent.

2. Beyond this depth of 21 in. up to 30 in. the soil-moisture remains constant. This may be a possible explanation as to why the deep-rooted crops can resist drought.

3. The phenomena of capillary rise of water in soil has been discussed and it has been shown that the upward movement of water in soil starts from the surface and gradually goes down.

4. The evaporation of soil-moisture under field condition can be satisfactorily expressed by the formula

$$\log (V—H) = K_1 t + \log K_2.$$

REFERENCES

Briggs, L. V. S. (1907). *Deptt. Agri. Div. Soil. Bull. No. 10.*

Burr, W. W. (1914). *Nebr. Agri. Expt. Stat. Research Bull.* **5**, 88.

Cameron, F. K. (1911). 'The Soil Solution'.

Green, H. (1928). *J. Agri. Sci.* **18**, 531.

Hall, A. D. (1904). 'The Soil', 94.

Keen, B. A. (1918). *J. Agri. Sci.* **9**, 396.

King, F. H. (1889). *Expt. Station Rec.* **12**, 34.

Leake, H. M. (1905). *J. Agri. Sc.* 454.

Leather, J. W. (1908). *Mem. Dept. Agri. Ind.* (*Chem. Ser.*). **1**, 6.

Mcdole, G. R. (1917). *J. Agri. Rec.* **9**, 27.

McGee, W. J. *U. S. A. Agri. Bur. Soils Bull.* 92 & 93.

Mitscherlich, E. A. (1913). *Bodenkunde Fur Land-und Fort-write*, 136.

Sen, A. T. (1930). *Mem. Dept. Agri. Ind.* (*Chem. Ser.*) **10**, 9.

MINERAL MATTER IN THE JUICE OF SUGARCANE AND ITS EFFECT ON THE RECOVERY OF WHITE SUGAR, I

BY

P. E. LANDER, M.A., D.Sc., F.I.C.,
Agricultural Chemist to Government, Punjab

AND

RAMJI NARAIN, PH.D., D.Sc.,
Assistant to the Agricultural Chemist, Punjab, Lyallpur

(Received for publication on 23rd March, 1936)

The sugar industry in India received considerable impetus after the imposition in 1932 of custom duty on white sugar imported into India, which led both in the Punjab and other provinces to the establishment of a considerable number of sugar factories. Prior to this date only a few refineries were working in the Punjab and manufactured white sugar from *gur* or jaggery imported from the United Provinces. These imported *gurs* were generally impure and soft in consistency, sometimes resembling dark-coloured, semi-viscous fluid but were invariably preferred to the *gurs* produced in the Punjab which were apparently cleaner and more attractive in appearance. The reason assigned for this partiality lay mainly in the alleged greater recovery of white sugar from the United Provinces *gurs*, and this was assisted by their lower price even after allowing for freight and other charges. The analyses for sugar content of a large number of Punjab *gurs* do not reveal any striking differences from the *gurs* produced in the United Provinces, although it has been suggested that the method of making *gur* as practised in the Punjab differs from the method in vogue in the United Provinces, in so far that in the former the juice is kept constantly stirred with a *mashad* or ladle not only during concentration but even after the thickened syrup has been transferred to the *gand* for solidification. It was suggested that this continual stirring tends greatly to reduce the size of the crystals in the *gur*, which would otherwise remain fairly large, and that this is responsible for the lower recovery of white sugar from Punjab *gurs*.

In order to ascertain the correctness of this view, it was decided to prepare *gurs* from the same variety of cane by both methods for analysis. That prepared by the United Provinces method took longer to solidify in the pan, was darker in colour and would not easily crumble and was so sticky that it could be drawn out into threads. In spite of these different physical features, the analytical data given in Table I did not show any difference which would account for these facts.

TABLE I

Analysis of gurs *prepared by the United Provinces and the Punjab methods*

Variety	Sugar in juice		Sugar in *gurs* prepared according to					
			U. P. method			Punjab method		
	Sucrose Per cent	Glucose Per cent	Sucrose Per cent	Glucose Per cent	Total sugar	Sucrose Per cent	Glucose Per cent	Total sugar
Co. 205 .	12·57	1·56	66·17	8·77	74·94	65·92	9·31	75·23
Co. 213 .	16·53	0·67	75·74	6·12	81·86	75·24	6·12	81·36
Co. 223 .	16·45	0·72	77·26	6·53	83·79	75·24	6·12	81·36

Some further analyses were undertaken in order to ascertain if differences in the climate and soil conditions in the United Provinces and in the Punjab respectively might account for any differences found in the sugars of the same cane varieties which might ultimately be reflected in the quality of the *gurs* produced from the two provinces. The data obtained are shown in Table II and, with the exception of Co. 290, did not show any pronounced difference in the sucrose and glucose content of some of the main varieties of sugarcane common to both provinces. It seems reasonable then to look in other directions for the alleged inferiority of the Punjab *gurs*.

TABLE II

Showing comparative analytical data for the same varieties of cane grown in the United Provinces (Shahjahanpur) and the Punjab (Jullundur)

Variety	Province	Juice	Sucrose per cent on cane	Glucose
Co. 213 . . .	U. P. . .	63·0	10·1	0·66
,, . . .	Punjab .	64·8	10·0	0·33
Co. 285 . . .	U. P. . .	66·0	9·1	..
,, . . .	Punjab .	62·5	9·5	0·18
Co. 293 . . .	U. P. . .	66·3	12·4	0·53
,, . . .	Punjab .	67·9	9·6	0·39
Co. 300 . . .	U. P. . .	65·3	12·4	0·36
,, . . .	Punjab .	67·2	11·3	0·26
Co. 312 . . .	U. P. . .	63·7	10·9	0·48
,, . . .	Punjab .	68·4	10·8	0·28
Co. 313 . . .	U. P. .	63·0	11·6	0·44
. . .	Punjab .	67·1	11·7	0·25

In sugar refineries the 'nett rendiment' values are used for determining the quality of raw sugars and are also employed as a check on the amount of white sugar actually obtained against the amount expected. This value takes into consideration the amount of sucrose, glucose and the ash or mineral matter present in the raw sugar and is calculated from the following formula :—

R = Polarisation — (I × glucose per cent) — (X × ash per cent)

The value of X in the above equation varies between 3·5 and 5 for different kinds and quantities of raw sugar produced in different localities and countries.

It is clear from the above that all the sucrose actually present in the raw sugar cannot be obtained as white sugar and that the amount left uncrystallised in the molasses is equal to the amount of reducing sugars + X times the amount of ash. The mineral matter, therefore, is of far greater account than the glucose content. The figures of analyses for *gurs* purchased from the markets in some of the important sugar producing centres are given in Table III.

TABLE III

Analytical data for gurs *from the Punjab and the United Provinces*

Description of sample	Polarisation or sucrose	Glucose	Ash	Nett rendiment
		Punjab		
Lyallpur . .	73·70	7·20	4·47	50·9
Jullundur . .	69·54	8·18	5·43	42·4
Amritsar . .	72·80	10·50	4·34	47·1
Sonepat . . .	66·43	11·32	5·49	36·0
Gojra (Lyallpur) .	71·40	7·90	6·00	42·5
AVERAGE . .	70·77	9·02	5·15	43·8
		United Provinces		
Gorakhpur . .	70·32	13·53	2·86	46·78
Do. . .	77·09	12·00	3·27	53·64
Do. . .	68·80	18·00	2·53	41·94
Muzaffarnagar .	74·00	11·70	2·53	53·40
Do. . .	70·00	13·20	2·38	48·50
AVERAGE .	72·04	13·69	2·71	48·85

It will be seen that the amount of sucrose in the Punjab *gurs* is practically the same as in *gurs* from the United Provinces, while the figures for glucose are decidedly lower. This means that the method of *gur*-making as practised in the Punjab is not inferior to the U. P. method, since any defect in the Punjab method would have resulted in inverting the sucrose and thus raising the glucose content. The main reason for the inferiority of the Punjab *gurs* is apparently their high mineral content, which is almost double that of the U. P. *gurs*.

This fact led to a systematic enquiry being undertaken into the causes responsible for the high ash content of the *gurs* manufactured in this province. The investigation has been carried on for the last three years and the results obtained so far are presented in this paper.

Apart from any adhering dust or soil particles which may gain access to the juice during the crushing of sugarcane, all mineral matter found in the *gur* can be traced to the soluble salts present in the juice from which the *gur* was prepared. This investigation, therefore, resolved itself into a study of the ash content of the juice from different varieties of cane grown in different localities.

During the year 1932-33, the Punjab possessed the second largest area under sugarcane—namely, 558,152 acres—of any province in India, the United Provinces standing first with 1,773,211 acres in the same year. This area must necessarily increase if the extra demand of new sugar factories, which have recently come into being, is to be met. The districts of Jullundur and Hoshiarpur comprise a tract which has for long been regarded as one of the most suitable for the production of sugar, although, from the climatic point of view, the south-eastern districts of Karnal and Rohtak appear to be better.

With the development of scientific methods in agriculture and the introduction of new varieties of sugarcane, other tracts such as the new colony areas, have also taken up the cultivation of this crop. It seems, therefore, that in spite of the unfavourable climatic conditions for the growth of sugarcane and competition with more paying crops such as cotton, the Punjab is likely to remain an important sugar-producing province. Punjab *gurs* give about five per cent less white sugar than the U. P. *gurs*, which means a great loss to the province and it is, therefore of importance to ascertain the causes responsible for the low quality of the canes alleged to yield inferior *gurs*.

The lines on which the investigation has been carried out are :—

1. Classifying sugarcane varieties according to the ash content of their juice.
2. Classifying different tracts in the province with reference to the ash content of the juice of sugarcane grown therein.
3. Studying the relationship that may exist between the ash content of sugarcane juice and the composition of the soil.
4. Investigating the possibilities of controlling the factors responsible for the high ash content of sugarcane juice in the Punjab.

1. Mineral content of different varieties of sugarcane grown in the Punjab

Table IV gives the results of analyses of different varieties of sugarcane from localities in different parts of the province. The figures for any one variety are generally the mean of several figures relating to that variety and were obtained after the cane had reached maturity. It is possible that the canes obtained from different localities might have been influenced by differences in climatic conditions

or in manurial treatments, but it will be seen that the mineral matter in cane varies from 0·24 per cent to 0·70 per cent only. The value of 0·24 for Co. 252 and Co. 300 refers to samples of these varieties obtained from Gurdaspur only, but as will be seen later, all varieties grown in this district show a very low ash content. Most of the varieties examined (12 out of 18) had an ash content in the neighbourhood of 0·50 per cent and only four contain more than 0·60 per cent. This difference of 0·1 per cent will affect the recovery of sucrose by only 0·4 per cent at the maximum, if these were the only varieties available to any particular factory, which is a very remote contingency.

TABLE IV

Analytical data for some of the important varieties of sugarcane grown in the Punjab

(Average figures)

Variety	Juice	Sucrose	Glucose	Total sugar	Total solids	Ash	Glucose ratio	Purity coefficient	Nett rendiment
Co.205	58·9	7·90	0·61	8·51	10·77	0·53	7·7	74·5	5·5
Co.213	67·4	9·45	0·41	9·86	11·71	0·55	4·4	80·7	7·1
Co.223	64·4	8·70	0·57	9·27	11·21	0·43	6·8	76·1	6·8
Co.244	66·1	9·55	0·41	9·96	11·93	0·67	5·4	78·6	6·8
Co.252	66·4	6·70	1·22	7·92	9·20	0·24	18·2	72·2	4·6
Co.270	64·9	9·60	0·39	9·99	12·15	0·46	4·4	80·0	7·6
Co.272	66·5	7·50	1·29	8·79	10·00	0·43	20·6	74·4	4·7
Co.281	68·5	10·92	0·21	11·13	13·28	0·53	2·4	82·4	8·8
Co.285	62·7	9·99	0·31	9·30	11·49	0·60	3·8	78·2	6·6
Co.287	64·2	8·50	0·80	9·30	11·01	0·46	9·4	77·6	6·0
Co.290	69·5	10·01	0·26	10·27	12·17	0·61	3·1	81·7	7·6
Co.300	69·0	9·20	1·00	10·20	11·00	0·24	10·9	83·6	7·4
Co.312	69·9	11·20	0·20	11·40	13·15	0·69	1·8	85·0	8·6
Co.313	68·1	11·10	0·27	11·35	13·00	0·55	1·4	85·6	8·9
Co.356	62·9	9·20	0·36	9·60	11·20	0·70	3·9	82·0	6·4
Katha	59·3	8·40	0·43	8·83	10·91	0·58	5·9	77·0	4·9
Suretha	60·0	9·08	0·19	9·27	11·30	0·52	7·1	80·1	2·1
Kansar	59·4	7·37	0·93	8·30	11·23	0·78	3·7	65·5	12·7

As pointed out by Thieme in 1930, it has been noticed in the Java factories that since 1915 the ash content of their cane juices has been increasing, particularly during the years 1926-29—a period which coincided with the production of P. O. J. 2878 cane. It appears that a high ratio of ash to non-sugars is a characteristic of modern canes, resulting in lower yields in the factory. In the case of the Punjab, however, taking the province as a whole, no striking differences in the mineral content of juice from different varieties at present available are noticeable.

It must be remembered, however, that where a number of varieties is available which shows highly favourable characters, such as high yields, high purity figures and low glucose ratios, those which have a low ash content must invariably be preferred and in propagating canes suitable for cultivation in the Punjab, this

question of ash content must receive full consideration especially in view of the fact that cane in the Punjab is liable to experience unfavourable climatic conditions.

2. Effect of soil and climatic conditions in different localities on the mineral content of the cane juice

Table IV gives the results obtained during the first year of the enquiry; eighteen varieties were examined from eight different districts, *viz.*, Hansi, Rohtak, Jullundur, Gujranwala, Lyallpur, Sargodha, Montgomery and Multan. In addition to the ordinary analyses of the juice, the amount of mineral matter was also determined in sixty-six samples. It is not proposed to give the analysis of each one of these separately as in the first year of the enquiry there was some difficulty in obtaining samples of certain varieties from all the localities at the same comparable period of growth. It was, therefore, decided to continue the investigation in the following year, under more comparable and better controlled conditions. The preliminary results obtained during the first year indicate that the province can be divided into three regions, *viz.*, sub-montane, central and western districts in relation to the amount of mineral matter present in the juice of sugarcane grown in different tracts.

In order to ascertain if any relationship exists between the amount of mineral matter in the cane juice and the amount of water-soluble salts present in the soil on which the cane grew, thirty-two soil samples were examined for total solids, carbonates, bicarbonates, chlorides and sulphates in a ten per cent water-extract of soil. It was anticipated that the amount of mineral matter present in the juice would be related to the amount of water-soluble matter in the soil, but contrary to expectations, the analytical results lent no support to this hypothesis.

The work carried out during the second year confirms all the conclusions arrived at the previous year. Before describing the results obtained, it may be as well to summarise the conditions under which the enquiry was conducted :—

(*i*) Since it had been found in the first year that, with one or two exceptions, the differences in the mineral content of the different varieties were not so great as the differences due to geographical situation, only four varieties which were available at all the localities selected were reserved for examination, *viz.*, Co. 213, Co. 285, Co. 290 and Co. 300.

(*ii*) In order to eliminate possible differences in mineral content due to difference in age, the canes were analysed at approximately the same period of growth. Thus, with the exception of Co. 213, which is a late ripener and was analysed once only in the third week of February 1933, the other three varieties were analysed twice in the season, *i.e.*, once in the middle of December 1932, before the onset of frost and again during the 3rd week of February 1933, when the canes were expected to have recovered completely from the effect of frost.

(*iii*) The crops selected had received no special manurial or other treatment likely to produce artificial variations in the chemical composition of the soil.

(*iv*) The localities selected were typical of the different soil and climatic conditions of the province.

(*v*) The mineral matter was determined in the unclarified juice, so that nothing was added to or removed from it.

As part of the enquiry, Co. 285 and Co. 290 were kept under observation with the object of studying variations in the composition of the juice at different periods of growth. The analyses were carried out at monthly intervals beginning in November 1932 and extending to the end of February 1933 and the results obtained are given in Table V. It will be seen that after the cane had reached maturity, the juice or soluble mineral matter varied but little. Thus a difference of some days or even a few weeks in the analysis will not effect to any great extent the relative amount of mineral matter present in the juice of different varieties or in the same variety from different localities. This explains why the general conclusions drawn from the first year's work (when in the case of some of the varieties the analyses were carried out at an interval of 2 to 3 weeks) are in no way modified by the more systematic and better controlled work in the following year.

TABLE V

Variations in the composition of the juice of sugarcane at different stages of its growth

Date of analyses	Percentage on cane							
	Juice	Sucrose	Glucose	Total sugar	Total solids	Ash	Nett rendiment	Purity
				Co. 285				
1st Nov. 1933.	63·5	7·38	0·38	7·76	9·84	0·66	4·68	75·0
1st Dec. 1933.	62·6	8·34	0·26	8·60	10·74	0·68	5·71	78·0
1st Jan. 1934.	61·9	8·38	0·11	8·94	10·55	0·62	6·56	83·7
31st Jan. 1934	62·8	8·72	0·20	8·92	10·85	0·63	6·30	80·4
27th Feb. 1934	60·0	8·92	0·06	8·98	11·58	0·72	6·34	80·5
				Co. 290				
1st Nov. 1933.	65·7	5·67	0·96	6·63	8·42	0·61	2·59	67·0
1st Dec. 1933.	70·0	9·91	0·26	10·17	11·84	0·68	7·28	84·0
1st Jan. 1934.	68·4	9·28	0·56	9·84	11·20	0·71	6·22	83·0
31st Jan.1934.	67·7	7·15	1·56	8·71	11·39	0·77	2·89	62·8
27th Feb.1934.	64·4	8·89	0·60	9·49	11·41	0·62	6·12	77·9

The results of the analyses of similar canes from different localities are given in Tables VI to IX. It will be observed that the greatest amount of mineral matter in the juice is to be found in canes from Multan, and the least in those

from Gurdaspur and Rawalpindi. The 'nett rendiment' values for Rawalpindi canes, however, are very much lower than for those from Gurdaspur. The reason apparently is that cold weather, particularly when the temperature at night falls, for any prolonged period, below the freezing point, brings about inversion of the sucrose already formed, resulting in an increase in the amount of glucose or invert sugar which prevents a corresponding amount of sucrose from crystallizing during the preparation of white sugar. On the other hand, a comparison of the figures for mineral matter obtained in December and February clearly indicates that frost has not affected them.

TABLE VI

Analytical data for Co. 213 from different localities in the Punjab

Locality	Date of analysis	Juice per cent	Sucrose per cent	Glucose per cent	Total sugar per cent	Total solid per cent	Ash per cent	Nett rendiment	Glucose ratio	Purity
Lyallpur	21st Feb. 1934	67·0	9·21	0·30	9·51	11·84	0·60	6·81	3·2	78
Sargodha	19th Feb. 1934	68·5	9·39	0·39	9·78	11·88	0·50	7·25	4·2	79
Montgomery	Not available									
Multan	17th Feb. 1934	68·2	7·8	0·18	7·98	9·7	0·72	5·10	2·3	80
Sirsa	23rd Feb. 1934	63·8	9·6	0·17	9·77	11·7	0·50	7·68	1·8	82
Jullundur	19th Feb. 1934	67·0	9·9	0·21	10·21	12·1	0·51	7·80	3·2	82
Gurdaspur	25th Feb. 1934	65·4	11·09	0·13	11·22	12·75	0·45	9·38	1·2	87
Rawalpindi	22nd Feb. 1934	68·8	9·00	0·72	9·72	11·44	0·31	7·19	8·0	79

TABLE VII

Analytical data for Co. 285 from different localities in the Punjab

Locality	Date of analysis	Juice per cent	Sucrose per cent	Glucose per cent	Total sugar per cent	Total solid per cent	Ash per cent	Nett rendimen.	Glucose ratio	Purity coefficient
Lyallpur	15th Dec. 1933	62·8	8·73	0·16	8·89	10·86	0·65	6·30	1·8	80
	21st Feb. 1934	63·4	9·56	0·07	9·63	12·03	0·69	7·07	0·7	80
Sargodha	16th Dec. 1933	62·8	8·89	0·35	9·24	10·9	0·64	6·30	4·0	82
	19th Feb. 1934	62·5	9·45	0·17	9·62	11·81	0·56	7·28	1·8	80
Montgomery	14th Dec. 1933	61·4	9·00	0·17	9·20	10·6	0·69	6·43	2·0	85
	18th Feb. 1934	64·4	9·70	0·17	9·87	11·9	0·74	7·44	1·8	82
Multan	16th Dec. 1933	62·3	8·80	0·10	8·90	10·7	0·85	5·71	1·1	82
	17th Feb. 1934	61·2	7·70	0·17	7·87	10·3	0·76	4·87	2·5	75
Hansi	15th Dec. 1933	57·4	7·90	0·36	8·30	9·8	0·53	5·78	4·6	81
	23rd Feb. 1934	60·0	9·20	0·20	9·40	11·5	0·51	7·21	2·8	80
Jullundur	13th Dec. 1933	62·0	8·10	0·63	8·70	10·8	0·37	6·17	7·7	75
	19th Feb. 1934	62·8	10·30	0·22	10·52	12·3	0·45	8·50	2·5	84
Gurdaspur	13th Dec. 1933	61·6	8·39	0·38	8·77	10·46	0·31	6·92	4·5	80
	25th Feb. 1934	61·9	10·20	0·22	10·42	11·90	0·41	8·54	2·2	86
Rawalpindi	15th Dec. 1933	63·3	6·41	1·07	7·48	9·31	0·39	3·98	16·6	68
	22nd Feb. 1934	62·7	7·40	0·96	8·36	10·52	0·43	5·89	13·0	70

Table VIII

Analytical data for Co. 290 from different localities in the Punjab

Locality	Date of analysis	Juice per cent	Sucrose per cent	Glucose per cent	Total sugar per cent	Total solid per cent	Ash per cent	Nett rendiment	Glucose ratio	Purity coefficient
Lyallpur	15th Dec. 1933	70·5	9·02	0·32	9·34	11·44	0·72	6·17	3·6	79
	21st Feb. 1934	67·6	8·47	0·84	9·31	12·40	0·65	5·35	9·9	68
Sargodha	16th Dec. 1933	68·3	10·3	0·29	10·60	11·60	0·57	8·01	2·8	89
	19th Feb. 1934	69·2	9·97	0·60	10·57	12·77	0·51	7·58	6·0	78
Montgomery	17th Dec. 1933	64·9	9·1	0·40	9·5	10·90	0·53	6·84	4·4	84
	18th Feb. 1934	62·1	9·1	0·40	9·50	11·21	0·55	6·77	4·4	81
Multan	Not available									
Hansi	15th Dec. 1933	63·7	9·5	0·22	9·70	11·02	0·60	7·20	2·3	86
	23rd Feb. 1934	70·0	9·3	0·23	9·53	13·00	0·70	6·62	2·8	72
Jullundur	19th Dec. 1933	71·0	11·5	0·65	12·20	13·03	0·26	9·94	5·8	88
	19th Feb. 1934	68·7	11·6	0·51	12·11	13·30	0·25	10·21	4·4	87
Gurdaspur	13th Dec. 1933	68·6	9·51	0·56	10·07	11·72	0·34	7·76	5·9	81
	25th Feb. 1934	67·5	12·34	0·14	12·48	13·72	0·41	10·76	1·1	90
Rawalpindi	15th Dec. 1933	68·2	9·17	0·49	9·66	11·49	0·42	7·21	5·4	80
	22nd Feb. 1934	67·7	7·61	1·98	9·59	11·60	0·30	4·58	26·0	66

Table IX

Analytical data for Co. 300 from different localities in the Punjab

Locality	Date of analysis	Juice per cent	Sucrose per cent	Glucose per cent	Total sugar per cent	Total solid per cent	Ash per cent	Nett rendiment	Glucose ratio	Purity
Lyallpur	15th Dec. 1933	68·5	8·92	0·36	9·28	11·17	0·67	6·23	4·1	80
	21st Feb. 1934	67·6	9·30	0·32	9·62	11·94	0·63	6·77	3·5	77
Sargodha	16th Dec. 1933	67·7	9·89	0·38	10·27	11·49	0·48	8·18	3·9	86
	19th Feb. 1934	67·9	9·92	0·35	10·27	12·48	0·50	7·82	3·5	80
Montgomery	17th Feb. 1933	65·3	9·90	0·14	10·00	11·0	0·44	8·23	1·4	90
	18th Feb. 1934	62·1	10·00	0·14	10·14	11·8	0·58	7·83	1·4	85
Multan	Not available									
Hansi	15th Dec. 1933	63·2	9·9	0·22	10·10	11·4	spoiled		2·2	87
	23rd Feb. 1934	65·6	8·4	0·25	8·65	11·9	0·51	6·36	3·0	71
Jullundur	13th Dec. 1933	70·1	7·8	1·01	8·80	10·0	0·58	4·76	12·9	78
	19th Feb. 1934	69·2	11·8	0·15	11·95	13·6	0·57	9·65	1·3	87
Gurdaspur	13th Dec. 1933	67·1	9·91	0·45	10·36	11·67	0·27	8·51	4·5	85
	25th Feb. 1934	67·1	11·88	0·22	12·10	13·17	0·31	10·57	1·7	90
Rawalpindi	15th Dec. 1933	70·9	9·89	1·25	11·14	12·23	0·48	6·96	12·6	81
	22nd Feb. 1934	70·0	7·88	1·49	9·37	11·05	0·27	5·44	19·0	71

It will be seen that, as a general rule, the mineral matter in the juice of all the varieties is least in the sub-montane tracts and increases progressively through the central districts towards the south-western arid tracts, where it attains the maximum value. The central regions, represented by the district of Jullundur and part of Hoshiarpur, produce canes with a medium mineral

content. This, combined with the fact that canes in this locality give the greatest yield of sucrose per acre, and experience a very long crushing season, as has been already pointed out by the authors [1935], might have been one of the factors which inadvertently exercised an influence in making this tract the home of the sugar industry in the past.

Similar variations also occur in the ash content of the juice of sugarcane grown in different localities in the United Provinces [Table X*]. It is interesting to note that the canes from Muzaffarnagar which is nearer to the source of the Jumna and the Ganges than Cawnpore, should be characterised by a low ash content, while those from Cawnpore which is much further away should possess a much higher content of mineral matter in their juice. It is difficult to say whether this is merely a coincidence or whether it reflects in any way conditions similar to those found in the Punjab where it is noticed that as we move with the rivers in a south-westerly direction so does the amount of mineral matter in the cane juice tend to increase. It is clear, however, that the ash content of the canes from the United Provinces is lower than that from the Punjab canes and this appears to be the only factor which detracts from their quality.

TABLE X

Ash content of the juice from the same varieties of sugarcane from different stations in the United Provinces

(*Percentage ash on juice by weight*)

Variety	Muzaffarnagar	Shahjahanpur	Cawnpore
Co. 213	0·270	0·374	0·578
Co. 281	0·287	0·432	..
Co. 285	0·497	..	0·685
Co. 300	0·278	0·559	0·515
Co. 312	0·269	0·409	0·381
Co. 313	0·381	0·406	0·664

3. Composition of the soil and the ash content of the juice of sugarcane growing thereon

As all the mineral elements present in plants are derived from the soil, it is necessary to examine the soil for a possible explanation of the peculiar behaviour of the same varieties of sugarcane in removing different amounts of minerals from different localities in the province. During the first year of this

* We are indebted to the Cane Agronomist, Muzaffarnagar, the Economic Botanist, Shahjahanpur, and the Agricultural Chemist, Cawnpore, for the supply of sugarcane juice of these varieties from their respective stations.

enquiry thirty-two samples of soil, on which the canes analysed were grown, were obtained from Jullundur, Gurdaspur, Gujranwala and Lyallpur and analysed for water-soluble salts. As has been remarked already no correlation was found to exist between these salts and the amount of mineral matter in the juice of the sugarcane. Thus, for instance, of the four places under observation, the Gurdaspur soil contained the largest amount of water-soluble salts, yet the canes from this place contained the least amount of soluble mineral matter in the juice.

Table XI gives the mechanical composition of some of the Punjab soils from which different varieties of sugarcane were obtained in the second year of this enquiry. It also includes the analyses of some typical sugarcane soils from the United Provinces and Bihar, while Table XII shows the figures for different water soluble ingredients of the same soils.

TABLE XI

Mechanical analyses of sugarcane soils

(*Average figures*)

Percentage on air-dried soil

Locality	Clay	Silt	Fine sand	Sand	Gravel
Pusa	7·20	45·80	46·60	0·41	..
Muzaffarnagar . . .	12·07	30·08	52·47	5·11	0·27
Shahjahanpur . . .	8·18	19·37	67·59	3·18	1·68
Gorakhpur . . .	11·14	33·99	45·31	9·44	0·12
Hansi	15·80	26·10	57·83	0·24	0·02
Montgomery . . .	12·45	31·66	54·66	0·98	0·25
Sirsa	6·70	13·40	79·03	0·78	..
Multan	13·88	31·94	53·82	0·31	0·06
Sargodha	11·42	30·40	45·48	12·60	0·10
Rawalpindi . . .	21·32	34·71	41·55	2·16	0·26
Gurdaspur . . .	10·84	28·90	38·58	21·55	0·13

It will be seen that, apart from the fact that the soils from the United Provinces and Bihar are slightly lighter than those from the Punjab, the soils from the three provinces do not reveal any striking differences in their mechanical constitution and the nature and composition of their water-soluble salts. Soils from Muzaffarnagar and Montgomery, as also from Gorakhpur and Sargodha are practically identical as far as their mechanical composition is concerned, but Sargodha and Montgomery soils do not produce as good a cane as do those from the other two places. Similarly, since soils from the United Provinces and Bihar contain less water-soluble salts than those from the arid regions (Multan and Montgomery) of the Punjab, a possible explanation of our problem may be found in this direction. It will be seen, however, that the Gorakhpur and

Sargodha soils, although they contain the same amount of water-soluble salts are not equally suitable as far as the quality of cane they produce is concerned. Again, Rawalpindi and Sargodha soils are identical in respect of the amount of water-soluble salts which they contain, but the former produces cane with the lowest amount of mineral matter in its juice of any in the Punjab. Thus it seems that differences in the mechanical composition of the soils and the salt content of their water extracts, do not provide a satisfactory explanation of the differences in the amount of mineral matter in the juices of cane obtained from different places.

TABLE XII

Analysis of sugarcane soils (average figures)

Ten per cent soil extract in water

Locality	Total solids	Carbonates	Bicarbonates	Chlorides	Sulphate
Pusa	0·155	0·010	0·103	0·029	..
Muzaffarnagar . . .	0·089	0·002	0·045	0·290	..
Shahjahanpur . . .	0·092	0·004	0·072	0·012	..
Gorakhpur . . .	0·126	..	0·068	0·025	..
Hansi	0·091	..	0·074	0·018	..
Sirsa	0·171	..	0·116	0·023	traces
Montgomery . . .	0·161	0·003	0·091	0·025	traces
Multan	0·179	0·003	0·085	0·035	0·075
Sargodha	0·131	..	0·095	0·012	..
Rawalpindi . . .	0·121	..	0·083	0·018	..
Gurdaspur . . .	0·080	..	0·051	0·014	traces

The analytical figures for hydrochloric acid-soluble salts for some of the typical soils from the above list are given in Table XIII. These indicate that, of the soils examined, those from Multan contain the highest amount of iron and aluminium. It is very difficult to gauge the extent to which differences in the amount of these two elements influence the quality of cane. It is worthy of note that the Pusa soils contain about 20 per cent of calcium, but only 0·158 per cent is present in the exchangeable form, recognised to be the more reactive state in which this element exists in the soil.

TABLE XIII

Chemical analyses of some typical sugarcane soil (hydrochloric acid extract)

Expressed as percentage on air-dried soil

Serial No.	Reg. No.	Description	Insoluble residue	Iron as Fe_2O_3	Aluminium as Al_2O_3	Calcium as CaO	Magnesium as MgO	Sodium and potassium as oxides	Phosphates as P_2O_5
1	364/34	Gurdaspur .	86·95	3·73	4·68	0·73	1·48	1·03	0·11
2	366/34	Gurdaspur .	87·64	3·50	4·86	0·63	1·10	0·91	0·10
3	221/34	Multan .	82·00	4·24	7·20	2·50	1·07	1·36	0·24
4	222/34	Multan .	80·54	4·78	7·46	2·45	1·14	1·47	0·17
5	12/34	Gorakhpur .	90·51	1·88	5·70	0·61	0·53	0·85	0·09
6	995/33	Pusa . .	54·50	1·45	4·16	21·00	1·42	1·00	0·20
7	997/33	Pusa . .	57·42	2·07	3·20	18·48	1·30	0·98	0·10

The exchangeable monovalent and divalent bases in these soils and the corresponding *p*H values are given in Tables XIV and XV.

The data in this table throw considerable light on the problem in hand, as it will be seen that the *p*H values of the soils from the arid regions are as a rule higher than those of the soils from the sub-montane, central or south-eastern regions.

It appears that soils with a *p*H value of 7 or less are best suited for the production of the highest quality juice, but this conclusion, which is based on the available data relating to the Punjab does not appear to be applicable to the United Provinces and Bihar soils. For example, the soils from Muzaffarnagar and Shahjahanpur have a *p*H value of 7, but those from Gorakhpur, Mushari and Pusa possess values approximating to those of soils from Sargodha and Lyallpur. This indicates that, while sugarcane does best on a soil with a *p*H value of approximately 7, it will tolerate those with values up to 7·7 and that the *p*H value of the soil alone is not necessarily an index of the quality of cane which it will produce. However, a better correlation seems to exist between the exchangeable calcium in the soil solution and the ash content of the juice.

The figures for the exchangeable calcium in the arid regions of the Punjab are very low, never being greater than 0·15 per cent on the soil. On the other hand, the soils from the United Provinces, Bihar and the Gurdaspur and Rawalpindi Districts of the Punjab, which produce canes with a low mineral content, show an exchangeable calcium figure lying between 0·15 and 0·20. The soil sample from Hansi, however, possessed the greatest amount of exchangeable calcium, namely 0·248, yet correspondingly the canes from Hansi did not show the lowest amount of mineral matter in their juice. With this single exception, a high content of exchangeable calcium in the soil seems to run *pari pasu* with low mineral figures in the juice. It is difficult to say in what precise way the exchangeable calcium in the soil affects this qualitative feature of the juice, but one obvious effect would be to render the soil better drained by improving its permeability to water.

TABLE XIV

Exchangeable bases in sugarcane soils

Serial No.	Reg. No	Description of the sample	*p*H value	Exchangeable K_2O	Exchangeable Na_2O	Exchangeable CaO	Exchangeable MgO	Ratio of monovalents to divalents
1	362/1934	Rawalpindi Agri. Farm . 1st foot	6·88	0·009	0·011	0·204	0·022	11·30
2	363/1934	Sargodha Agri. Farm . ,, .	7·56	0·096	0·008	0·152	0·022	1·67
3	364/1934	Gurdaspur Agri. Farm . ,, .	6·74	0·015	0·013	0·181	0·084	9·48
4	365/1934	Ditto . ,, .	6·78	0·005	0·017	0·174	0·049	10·12
5	366/1934	Ditto . ,, .	6·78	0·004	0·052	0·150	0·048	3·54
6	367/1934	Ditto . ,, .	6·91	0·007	0·054	0·159	0·051	3·46
7	106	Hansi Agri. Farm . . ,, .	6·83	0·011	0·048	0·258	0·040	5·05
8	107	Ditto . ,, .	7·24	0·006	0·044	0·234	0·032	5·32
9	108	Ditto . ,, .	7·05	0·0045	0·058	0·252	0·044	4·70
10	109	Sirsa Agri. Farm . . ,, .	7·38	0·005	0·034	0·136	0·015	3·86
11	212	Montgomery Agri. Station ,, .	7·58	0·022	0·022	0·123	0·039	3·69
12	213	Ditto . 2nd foot	7·90	0·024	0·008	0·112	0·036	4·63
13	214	Ditto . 3rd foot	7·58	0·005	0·005	0·106	0·023	12·90
14	215	Ditto . 1st foot	8·10	0·052	0·032	0·126	0·040	1·96
15	216	Ditto . 2nd foot	8·08	0·029	0·008	0·083	0·024	2·89
16	217	Ditto . 3rd foot	8·18	0·016	*Nil*	0·061	0·028	5·57
17	218	Multan Agri. Farm . . 1st foot	8·08	0·032	0·005	0·094	0·016	2·97
18	219	Ditto . 2nd foot	7·81	0·025	0·005	0·082	0·012	3·13

TABLE XIV—*contd.*

Serial No.	Reg. No.	Description of the sample	*p*H value	Exchangeable K_2O	Exchangeable Na_2O	Exchangeable CaO	Exchangeable MgO	Ratio of monovalents to divalents
19	220 . .	Multan Agri. Farm . 3rd foot	7·71	0·029	0·012	0·142	0·016	3·85
20	221 . .	Ditto . 1st foot	8·08	0·044	0·022	0·112	0·016	1·94
21	222 . .	Ditto . 2nd foot	7·95	0·041	0.082	0.112	0·012	1·00
22	223 . .	Ditto . 3rd foot	7·81	0·002	0·035	0·115	0·018	3·33
23	6 . .	Village Surju, Dist. Muzaffarnagar .	6·83	0·005	0·003	0·166	0·020	23·25
24	7 . .	Village Kukra, Dist. Muzaffarnagar .	7·08	0·042	0·041	0·162	0·024	2·24
25	8 . .	Village Musa, Dist. Muzaffarnagar .	6·83	0·015	0·009	0·179	0·024	8·45
26	9 . .	Narainpur, Dist. Shahjahanpur . .	7·11	0·017	0·011	0·197	0·016	7·60
27	10 . .	Banwaripur, Dist. Shahjahanpur .	7·19	0·022	0·019	0·199	0·032	5·63
28	11 . .	Atsillia, Dist. Shahjahanpur . .	..	0·019	0·019	0·200	0·008	5·47
29	12 . .	Maharajgunj, Dist. Gorakhpur . .	6·88	0·018	0·005	0·156	0·020	7·67
30	13 . .	Dharudumat, Dist. Gorakhpur . .	7·71	0·021	0·014	0·218	*Nil*	6·23
31	14 . .	Padvanna, Dist. Gorakhpur . .	8·01	0·026	0·008	0·174	0·028	5·94
32	995/1933 .	Mushari Sugar Research Station .	7·93	0·042	0·023	0·119	0·032	2·33
33	996/1933 .	Ditto . . .	7·45	0·026	0·046	0·187	0·016	2·82
34	997/1933 .	Pusa Research Institute . . .	7·68	0·055	0·006	0·156	*Nil*	2·57
35	998/1933 .	Ditto . . .	7·63	0·012	0·012	0·159	0·005	6·83
36	..	Lyallpur Normal Soil Sq. 27 . .	7·40	0·0268	0·029	0·140	0·014	2·75

TABLE XV

Exchangeable bases in sugarcane soils (average figures)

Serial No.	Description	*p*H value	Exchangeable K_2O	Exchangeable Na_2O	Exchangeable CaO	Exchangeable MgO
1	Rawalpindi	6·88	0·009	0·001	0·204	0·022
2	Sargodha	7·56	0·096	0·008	0·152	0·022
3	Gurdaspur	6·80	0·008	0·034	0·167	0·058
4	Hansi	7·04	0·007	0·050	0·248	0·039
5	Sirsa	7·38	0·005	0·034	0·136	..
6	Montgomery	7·90	0·049	0·015	0·102	0·031
7	Multan	7·91	0·029	0·027	0·110	·010
8	Muzaffargarh	6·94	0·021	0·018	0·169	..
9	Shahjahanpur	7·16	0·019	0·016	0·179	0·019
10	Gorakhpur	7·53	0·022	0·009	0·183	·021
11	Mushari	7·69	0·034	0·035	0·153	0·024
12	Pusa	7·66	0·035	0·009	0·158	·005
13	Lyallpur	7·60	0·027	0·029	0·140	0·014

Table XVI shows the relative permeability of some of these soils to water and it appears that the intake of salts by the cane is greatly influenced by the permeability of the soil on which it grows.

TABLE XVI

Showing relative permeability to water of different soil samples

Locality from which soils were obtained	C.c.s of water percolating through a 18·5 cm. column of soil in 4 hours	Exchangeable calcium
Shahjahanpur (Narainpur)	67·0	0·197
„ (Banwaripur)	29·0	0·199
Gorakhpur (Maharajgunj)	38·0	0·156
„ (Dharudumat)	18·6	0·218
Gurdaspur (Agricultural Station)	31·6	0·181
„ „	24·5	0·174
Muzaffarnagar (Surja)	8·4	0·166
„ (Kukra)	9·6	0·162
Mushari (Sugarcane Station, Bihar)	8·4	0·119
Pusa (Imperial Agricultural Institute Farm)	9·5	0·156
Lyallpur (Agricultural Farm)	7·9	0·140
Montgomery „	6·4	0·123
„ „	8·8	0·126
Multan „	2·1	0·094
„ „	6·2	0·112

4. Possibilities of controlling the juice-soluble mineral matter in the sugarcane crop in the Punjab

If there is an abundance of soluble inorganic salts present in the soil, most plants will absorb a greater quantity than is necessary for their maximum growth. Thus, Jordon [1913] in his nutrition experiments with barley, peas, tomatoes, tobacco, buckwheat and rape found that both phosphorus and potash compounds increased in these plants after the maximum increase in growth had been reached. As already noted, however, we did not find any direct relationship between the amount of soluble salts present in the soil and the mineral content of the sugarcane juice. The above observation of Jordon, however, refers not to the expressed sap but the whole plant. Further, it has been noted that the amount of a given element in a plant may be influenced by the proportion and kind of other elements contained in the soil or culture solution. Thus Ginsburg [1925] found that withholding phosphorus increased the ash content of the soybean plant from 13·3 per cent to 18·6 per cent and similarly withholding manganese increased it to 18·4. The figures (Table XVII) obtained at Lyallpur indicate the possibility of modifying the composition of the plant by changing the proportions of different elements in the soil, and in view of the findings of Lipmann [1904] that the nature of the salts present in the juice exercise a profound effect in determining the amount of sucrose withheld from crystallising (as shown below) the above observations are of considerable importance. Lipmann refers to Lagrange who showed that when present in pure sugar solution, one part of the following salts will prevent sugar from crystallising in amounts shown against each :—

	Amount of sugar prevented from crystallising out
	Parts
NaCl	0·0
CaCl	0·5
Na_2SO_4	2·0
KCl	3·0
K_2SO_4	3·5
Na_2CO_3	3·5
K_2CO_3	3·5
Na_3PO_4	5·0
KNO_3	5·5
$NaNO_3$	6·5

TABLE XVII

Mineral composition of wheat plant grown on soils saturated with different cations (metals)

Nature of cation	Ash	Insoluble residue	Iron and alumi-nium	Calcium	Magne-sium	Manga-nese	Sodium	Potas-sium
Calcium . .	17·95	5·82	1·218	1·424	0·698	0·010	0·855	3·87
Magnesium .	15·74	4·16	0·735	0·057	1·192	0·010	1·380	4·87
Manganese . .	10·04	2·63	0·579	0·746	0·522	1·215	0·288	2·49
Potassium . .	20·40	4·47	0·639	0·590	0·530	0·012	0·796	9·41
Normal soil .	11·41	...	...	0·470	0·310	0·012	0·710	2·97

Lipmann refers in detail to the investigations of a number of workers such as Marschal, Williamson, Nugues, Herzfeld, and others, on the determination of the molasses forming power of different salts and draws the general conclusion that the recovery of white sugar from sugarcane juice is influenced not only by the amount of mineral matter but also by the nature of the salts present in the juice. It has further been seen that the nature and amount of salts taken up by plants depend upon the composition of the soil or culture medium in which they grow. These observations suggest the possibility of decreasing the amount of mineral matter in cane juice (particularly in regard to certain ingredients) by treatment of the soil on which the cane grows. As has already been pointed out soils with a high exchangeable calcium content have yielded canes with a low ash content.

It appears, therefore, that it should be possible in the Punjab to produce canes with the lower ash content than at present by increasing the exchangeable calcium in the soil by a judicious application of calcium salts. It has already been found at Montgomery that the juice of sugarcane (Co. 285) from soil treated with gypsum gives 0·98 gr. of ash per 100 c.c. against 1·12 from an untreated soil. Further, Hurst and McKaig [1933] found that the application of nitrogen fertilisers increased the nitrogen content of cane juice to an appreciable extent and also decreased the ash content of the juice as compared with juice from cane grown on unmanured soil. On the other hand they found that the potassic or phosphatic fertilisers increased the ash content of the juice. In order to throw further light on these features, a series of experiments under controlled conditions, using calcium and nitrogen fertilisers, have been started at Multan, Lyallpur and Gurdaspur, and the results will be presented when available.

SUMMARY

1. Sugar refineries in the Punjab have always shown a preference for *gur* or jaggery from the United Provinces over the local commodity, on the plea that the former yields a greater percentage of white sugar. It was at one time believed

that the smaller recovery of cane sugar from Punjab *gurs* was due to the defective method of their preparation, resulting in the breaking down into smaller fragments of the larger-sized crystals of sucrose by constant ladling and stirring of the juice and the thickened syrup as practised by the Punjabi *gur* boiler—an obviously unacceptable explanation.

2. It has, however, been found that the low recovery is due to the greater amount of mineral matter present in the Punjab *gurs*, which is the result of the high ash content of the cane-juice from which these are prepared.

3. Apart from the higher ash content of their juice, the Punjab canes are in no way inferior to those from the United Provinces and Bihar ; they contain as much sucrose as those from the two latter provinces and much less glucose.

4. Since all mineral matter in plants and crops is derived from the soil on which they grow, the high mineral content of the juice from the Punjab canes must be correlated with the composition of the Punjab soils. It has been shown that in mechanical composition and the nature and amount of their water- and acid-soluble salt content, the sugarcane soils of the Punjab are almost identical with those from the other two provinces, but they differ in the amount of exchangeable calcium. This in conjunction with a slightly higher *p*H value seems to be the most likely explanation of the greater ash content of the juice from sugarcane grown in the Punjab.

5. It is suggested on the analogy of the wheat plant that it may be possible to modify the ash content of the cane juice by treatment of the soil with certain chemicals and manures. Experiments with this object in view are in progress at different centres in the province and the result will be communicated when ready.

The author's thanks are due to Syed Asghar Ali Shah, Research Assistant, for help in analyses.

REFERENCES

Ginsburg, J. M. (1925). *Soil Science* **20**, 1-15.

Hurst, L. A. and MacKaig, M. (1933). *Sugar Bull.* **11**, 7-7.

Jordon, W. H. (1913). *Bull.* 158 and 160 *I. N. Y. Agri. Expt.*

Lander, P. E. and Ramji Narain (1935). *Ind. J. Agric. Sci.* **5**, 2, pp. 213-345.

Lipmann (1904). *Chemi der Zuckerartan.*

Theime, J. G. (1930). *Br. Chem. Abs.*, 1931, p. 599.

THE PROBLEM OF THE NITROGEN SUPPLY OF RICE

I. FIXATION OF NITROGEN IN THE RICE SOILS UNDER WATER-LOGGED CONDITIONS

BY

PRAN KUMAR DE

Agricultural Chemistry Section, Dacca University

(Received for publication on the 23rd July 1936)

An excerpt from Crop Production in India by Albert Howard is given below to introduce the subject under investigation. Referring to the phenomenon of nitrogen-supply of rice, Howard states :

" In any scientific consideration of the soils which produce the rice crop in India, practical experience at first seems to contradict one of the great principles of the agricultural science of the Occident, namely, the dependence of cereals on nitrogenous manures. Large rice crops are produced in many parts of India on the same land year after year, without the addition of any manure whatever. The rice fields of the country export paddy in large quantities to the centres of population or abroad, and there is no corresponding import of combined nitrogen. Taking Burma as an example of an area exporting rice beyond seas, during the last twenty years about 25,000,000 tons of paddy have been exported from a tract roughly 10,000,000 acres in area. As unhusked rice contains about 1·2 per cent. of nitrogen, the amount of this element shipped overseas during the last twenty years or destroyed by the burning of the husk is in the neighbourhood of 300,000 tons. As this constant drain of nitrogen is not made up by the import of manure, we should expect to find a gradual loss of fertility. Nevertheless this does not take place either in Burma or in Bengal, where rice has been grown on the same land year after year for centuries. Clearly the soil must obtain supplies of nitrogen from somewhere, otherwise the crop would cease to grow. The only likely source is the fixation from the atmosphere and the question arises how can this take place in a Bengal rice field, for example."

There are obviously two possibilities to account for the ability of rice to grow in the same soils year after year even in absence of any manure. Either sufficient nitrogen is fixed from the atmosphere and rendered available in the soil to compensate for the amount removed with the crop and lost otherwise or the plants themselves are able to assimilate elementary nitrogen like legumes. Although in the present state of our knowledge an assumption that a cereal crop like rice can fix atmospheric nitrogen will hardly receive any support, nevertheless this possibility deserves very careful examination in view of the fact that Sen [1929] has demonstrated the occurrence of a nitrogen-fixing organism within rice root while Viswanath [1932] obtained indications that rice plant may possess the power of fixing nitrogen.

In studying the fixation of nitrogen in the rice soils, it should be remembered that these soils remain alternately dry and water-logged. From transplantation to harvest, soils remain water-logged : thereafter up to the next transplantation they are allowed to remain dry and fallow. In the water-logged state the conditions become distinctly unfavourable to the beneficial flora of the soil such as *Azotobacter*, and it is, therefore not expected that any bacterial fixation of nitrogen will take place at this period. But the abundant growth of the algal film very often observed on the surface of the submerged rice soils, deserves very serious consideration. The beneficial effect of these organisms in aerating the roots of the rice plant and the upper layers of the submerged soils have been observed by Harrison and Aiyer [1914]. Nothing, however, is known whether they are able to fix nitrogen, though Howard [1924] suggested that ' the algae and bacteria in the film, working conjointly, are capable of using the energy of sunlight to fix some of the nitrogen evolved in fermentation in a form suitable to the rice plant '. Several investigators have described a symbiosis with the nitrogen-fixing bacteria on the part of algae ; others have affirmed in a belief that algae themselves are able to fix (direct) nitrogen. For earlier literature on this subject, reference may be made to a paper by Bristol and Page [1923] whose very careful experiment has shown that green algae in pure cultures cannot fix elementary nitrogen. Amongst the recent workers, Lipmann and Teakle [1925] observed that an association between *Azotobacter* and *Chlorella* led to an increased fixation of nitrogen though Hoover and Allison [1935] claim that certain *Nostoc* are able to fix nitrogen in pure cultures.

Some fixation is also possible during the dry period, particularly in the winter when the conditions of the soils, as regards temperature and moisture, are eminently suitable for the growth of *Azotobacter* and other nitrogen-fixing bacteria. The average soil-temperature at this stage is about 25°C. and the moisture-content is sufficiently low to secure aerobic conditions. Moreover, a portion of the straw is usually left in the fields after harvest which may be utilised by the nitrogen-fixing bacteria as source of energy.

Besides the fixation from the atmosphere, soils may receive nitrogen from other sources as well. With dew, rains, etc., a small amount of nitrogen may be added. Leather [1906] calculated that in North India about 3·2 lbs. of nitrogen are added per acre of land in this way. Deposition of silts is another important factor but the supply from this source is restricted only to the areas irrigated with river water.

The investigations outlined above were started in this laboratory in 1931 and the results obtained so far will be described in this series of papers.

Experimental

The first experiment of the series was performed in 1932 with a few samples of soils collected from different plots of the Government Farm at Dacca. Fifteen

grms. portions of air-dried and sieved soils were water-logged with the addition of 100 c.c. of distilled water in 300 c.c. Erlenmeyer flasks. The flasks were divided into two sets—one set was exposed to sunlight and the other was kept in the dark. Determination of total nitrogen after three months showed that the soils kept in the light gained slightly in nitrogen while there was significant loss from those in the dark. The experiment was repeated several times and the previous observations confirmed. The results of one of the experiments are given in Table I.

Very encouraging results were obtained when similar experiments were performed with a sample of soil obtained from the district of Faridpur. In this soil a greenish algal growth appeared soon after water-logging and exposure to sun, which gradually increased in bulk and eventually became so heavy that the entire surface of the soil was covered with a thick growth of it. Determination of total nitrogen after three months showed considerable gain. As in Dacca soil, slight loss of nitrogen took place in the dark.

TABLE I

Showing the fixation of nitrogen in Dacca and in Faridpur soils under water-logged conditions

(Nitrogen as p. p. m.)

Soil	*N* at start	*N* after exposure to sunlight
DACCA.		
Plot North Hazi . . .	900	952, 924, 933, 925.
Plot East Ravina . . .	1312	1344, 1325, 1325.
Faridpur	639	887, 887, 802.

Considering the importance of the results obtained with Faridpur soil in their bearings on the present problem, it was proposed to repeat the above experiment with a large number of replicates in order to confirm the previous observations. Accordingly the experiment was repeated in 1933 and again in 1934. The results of the latter experiment are given in the following table.

TABLE II

Showing the fixation of nitrogen in Faridpur soil

N as p. p. m.

N at start	N after exposure
635	784, 829, 802, 847, 856, 847, 865, 811.

In order to observe the influence of temperature and other environmental conditions on the fixation of nitrogen, the above experiment was performed both in the summer and in the winter but no appreciable differences were observed in the amounts of nitrogen fixed under the two conditions.

Attempts were next made to account for the low nitrogen fixing capacity of Dacca soil. It will be noticed that there was a heavy growth of algae in Faridpur soil exposed to light in which considerable fixation of nitrogen also took place. On the other hand the growth in the corresponding Dacca soil was very poor and absolutely no growth appeared in any of the soils kept in the dark. And in these cases, little or no fixation of nitrogen took place. It was, therefore, thought that these algae play an important role in the fixation of nitrogen and their failure to develop in Dacca soil is the cause of its low nitrogen-fixing capacity. Two reasons may be suggested to account why the growth was so poor in Dacca soil : the organisms themselves may not be present in the soil in an active condition or the conditions of the soil might not be favourable for their growth. If former is the cause, there should be an increased fixation of nitrogen in the soil if it is inoculated with the appropriate organisms. But if the latter, no such increase will take place. This was tested by water-logging and exposing to sunlight 15 grms. portions of soil (14 grms. of Dacca soil + 1 grm. of Faridpur soil) and determining total nitrogen at the end of the experiment. The amounts fixed under these conditions were not sensibly different from those fixed in Dacca soil alone. Obviously the conditions obtaining in Dacca soil were not favourable for the growth of the organisms supplied with Faridpur soil. On comparing the properties of these two soils, an important difference was found in their reaction. Whereas, Faridpur soil is slightly alkaline (pH 8·2), Dacca soil is acidic (pH 4·9). Suspecting that the low pH of Dacca soil was the factor inhibiting the growth of the organisms responsible for the fixation of nitrogen, 15 grms. portions of the soil were water-logged after addition of 1 grm. of $CaCO_3$ and the mixtures exposed to sunlight. Soon a growth similar to that observed in Faridpur soil appeared in the cultures and the determination of nitrogen showed considerable increase (Table III). It is, therefore, clear that the organisms were already present in the soil but they could not grow owing to the acid reaction of the soil.

TABLE III

Showing the fixation of nitrogen in Dacca soil after treatment with $CaCO_3$

Nitrogen as p. p. m.

——	N at start	N after exposure to sunlight
DACCA SOIL		
Plot North Hazi . . .	821	1073, 1073, 1017, 989, 1026.
Plot East Ravina . . .	1296	1428, 1530*, 1700*, 1578*, 1587* 1730*.

* Exposed to sunlight for 7 months ; the remaining cultures were exposed for 3 months.

Next, in order to ascertain whether the fixation of nitrogen in the water-logged state is a special property possessed only by Dacca and Faridpur soils or by the rice soils in general, a number of rice soils were collected from different parts of India and the fixation of nitrogen in them was studied, the procedure being identical with that described before. The result are given in Table IV.

TABLE IV

Showing the fixation of nitrogen in different soils

Nitrogen as p. p. m. on air-dry basis

Soil	*p*H	N at start	N after exposure	Gain
Rajshahi, Bengal . . .	8·20	1069	1402	333
Bhagalpur, Bihar . . .	8·45	940	1270	330
Coimbatore, Madras . .	8·13	789	1064	275
Raipur, C. P. Dorsa . .	7·76	849	961	112
Raipur, C. P. Matasi . .	7·63	448	546	98
Karjat, Bombay . . .	7·66	588	723	135
Rangpur, Bengal . . .	6·20	1036	1185	149
Insein, Burma . . .	5·10	562	641	79
Sylhet, Assam (B) . . .	4·95	1097	1138	41
Sylhet, Assam (C) . . .	4·98	1566	1577	11

In the above experiment, total nitrogen at start, was determined both by Kjeldahl method modified to include nitrate and by the ' wet digestion ' method of Srinivasan [1932].

The results in Table IV show that considerable amount of nitrogen has been fixed in the soils having slightly alkaline reaction. In these soils, very heavy growths, similar to that observed in Faridpur soil, appeared soon after water-logging. In some cases, the growths were so thick that the entire soil mass remained embedded within them. On the other hand, little or no growth was observed in soils with lower *p*H, though on the addition of lime, even these soils showed good growths. It appears very probable that the growths appearing in the different soils are not alike. There is considerable difference in the shades of their colour. Growth from Dacca soil was nearly colourless, from Coimbatore soil brown, from Faridpur soil light green while those appearing in Rajshahi and Bhagalpur soils were deep green.

It was next intended to see whether on treatment with lime the nitrogen-fixing capacities of the soils specially of those having low *p*H could be improved as has been done in the case of Dacca soil. For this purpose 15 grms. portions of each of the following soils were mixed with 1 grm. of $CaCO_3$ and the mixtures water-logged in the usual way. In every case, the growths were much better than in the untreated soils. The results (Table V) show the beneficial effect of lime on the fixation of nitrogen in water-logged soils.

TABLE V

Showing the effect of lime on the fixation of nitrogen. Nitrogen as p. p. m. on air-dry basis.

Soil	N fixed	
	without lime	with lime
Sylhet, Assam (B)	41	116
Sylhet, Assam (C)	11	142
Rangpur, Bengal	149	205
Insein, Burma	79	138
Karjat, Bombay	135	308

ON THE NATURE OF THE ORGANISMS RESPONSIBLE FOR THE FIXATION OF NITROGEN IN WATER-LOGGED SOILS

From the observations made with Dacca and Faridpur soils, it is evident that the fixation of nitrogen in water-logged soils is not a bacterial process. For, if it were bacterial, not only fixation would have taken place in the dark but perhaps greater amount would have been fixed under this condition than in the sunlight on account of the germicidal property of the latter. The following experiment shows that bacteria actually fix more nitrogen in the dark than in the light.

A number of Erlenmeyer flasks each containing 100 c.c. of Ashby's solution were each inoculated with 1 grm. of Faridpur soil. For experiment in the dark, the flasks were painted outside by a thick coating of Japan Black and covered with small beakers similarly painted. The flasks were exposed to sunlight for two weeks after which total nitrogen was determined. The results are given in the following table.

TABLE VI

Showing the influence of sunlight on the fixation of nitrogen by bacteria

N as mgrm. fixed per 100 c.c. of Ashby's solution

Dark	Light
9·1	6·0
8·5	5·7
6·7	6·4
8·1	8·5
10·1	8·5
Mean . . 8·5	7·1

It was next thought that the algae that appeared in the soils on water-logging, are the active agents. To ascertain whether these algae actually possess the power of nitrogen-fixation, a little growth from Faridpur soil was inoculated into a medium containing the necessary minerals but no combined carbon or nitrogen and the solution exposed to sunlight. Within a week, a greenish growth was appearing at first on the inner bottom of the flasks but gradually rising up to the surface of the solution. At the end of two months scattered growths, both floating and submerged, were seen throughout the solution. The growths were slimy, pale green in colour and had large bubbles of gases enclosed within their mass. Determination of total nitrogen showed an average fixation of 3·6, mgrm. of nitrogen per 100 c. c. of the culture solution. From this experiment, as well as, from the observations that considerable amount of nitrogen was fixed in those cases where algal growth was abundant, it is concluded that the fixation of nitrogen in water-logged soils is an algal process. But as the above experiment was performed with crude cultures, it is not possible to say at present whether the fixation is brought about by algae themselves or by algae working in symbiosis with bacteria. The first step in the settlement of this question is obviously to obtain the different species of algae in a state completely free from bacteria. The individual species may then be tested for their nitrogen-fixing power. Attempts were accordingly made to purify the algal cultures by successively sub-culturing them in a medium free from combined carbon and nitrogen. The composition of the medium is given below. As this medium is not suitable for the growth of bacteria and other non-nitrogen-fixing organisms, it was thought that they would be eliminated after a few sub-cultures.

K_2HPO_4	0·5 grm.
$MgSO_4, 7H_2O$	0·2 grm.
$CaSO_4$	0·1 grm.
$FePO_4$	0·1 grm.
$Ca_3(PO_4)_2$	1·0 grm.
$FeCl_3$	Trace.
H_2O (glass distilled)	1000 c.c.

Sub-cultures were made by transferring asceptically one drop of a thoroughly shaken suspension of the growth from the previous culture to 100 c. c. portions of sterilised medium. The amounts of nitrogen fixed by different sub-cultures are shown in the following table.

TABLE VII

Showing the amounts of nitrogen fixed by different sub-cultures

	N as mgrm. fixed per 100 c. c. of the medium
First subculture	3·6
Second „	2·6
Third „	7·6*
Fourth „	2·2
Fifth „	2·1

Several of the above cultures were kindly examined by Professor F. E. Fritsch F.R.S., of the Queen Mary College, London. The following extract from his report will show the conditions of the cultures after purification. Referring to the fifth sub-cultures, Professor Fritsch says :

" Tube No. 1 contains a blue-green alga, together with what I take to be a number of fungal hyphæ and a good deal of an undeterminable green unicellular alga. The blue-green alga, which makes up the bulk of the sample, is a species of *Phormidium* closely related to *P. orientale* West. It differs from the published descriptions in narrower width, shorter cells, and the pale colour of the trichomes. Very occasional threads, however, have the elongate cells of the type. I should be inclined to suspect that the shortness of the cells might be a result of rapid cell-division under cultural conditions and would, therefore, regard the material as a cultural form of *Phormidium orientale* showing the differences above enumerated."

He has further reported that ' several of your cultures also contain Bacteria and perhaps Fungi '.

Consequently it is not possible to say at this moment whether the fixation of nitrogen in water-logged soils is the result of the activities of algae alone or of algae working in symbiosis with either bacteria or fungi. The author hopes to carry out this work further in the laboratory of Professor Fritsch and the results that will be obtained there will be published in a separate paper.

SUMMARY

(1) Several rice-soils collected from different parts of India were studied with regard to their power to fix nitrogen under water-logged conditions.

(2) Fixation of nitrogen took place in all of the soils examined, when they were water-logged and exposed to sunlight for three months.

(3) Soils having slightly alkaline reaction fixed much more nitrogen than those with lower *p*H. In the former soils, a heavy algal growth appeared soon after water-logging but in the latter the growth was much poor.

(4) The addition of calcium carbonate to the soils having acid reactions stimulated both algal growth and also nitrogen fixation.

* Exposed to sunlight for 11 months ; the rest were exposed for 2 months.

(5) It has been shown that bacteria fix more nitrogen in the dark than in presence of sunlight.

(6) From the evidences available, it is concluded that the fixation of nitrogen in water-logged soils is an algal process, though it has not yet been possible to decide whether the fixation is brought about by algae alone or in symbiosis with other organisms.

The author's thanks are due to Professor J. C. Ghosh for his interest in this work, and also to the Imperial Council of Agricultural Research for their financial help.

REFERENCES

Bristol, B. M. and Page, H. J. (1923). *Ann. App. Biol.* **10**, 378.

Harrison, W. H. and Aiyer, S. P. A. (1914). *Mem. Dept. Agric. India (Chem. Ser.)* **4**, No. 1.

Hoover, S. R. and Allison, F. E. (1935). *Trans. Third Inter. Cong. Soil Science*, 1-5.

Howard, A. (1924). Crop Production in India. P. 114.

Leather, J. W. (1906). *Mem. Dept. Agric. India (Chem. Ser.)* **1**, No. 1.

Lipman, C. B. and Teakle, L. J. H. (1925). *Journ. Physiol.* **7**, 509.

Sen, J. N. (1929). *Agric. J. India*, **24**, 229.

Srinivasan, A. (1932). *Ind. J. Agric. Sci.* **2**, 525.

Viswanath, B. (1932). Society of Biological Chemists, India, Annual Publication.

INHERITANCE OF EARLINESS IN UNITED PROVINCES RICES, I

BY

R. L. SETHI, M.Sc. (Pb.), B.Sc. (Agri.—Edin.), I.A.S.,
Economic Botanist (Sugarcane and Paddy) to Government, U. P.,

B. L. SETHI, M.Sc., Ph.D. (Wales),
Assistant Paddy Specialist, Rice Research Station, Nagina,

AND

T. R. MEHTA, B.Sc.,
Research Assistant, Rice Research Station, Nagina.

(Received for publication on 21st July 1936)

(With four text-figures)

Introduction

The following account is the result of hybridization studies in earliness in crosses made in rice for achieving economic ends. Data have been accumulated up to the F_5 stage, and a few strains of promise have been extracted. All along the course of the work, earliness was one of the chief bases of selection, hence close study of the inheritance of earliness had to be pursued. The results are reproduced here because, except for two papers by Ramiah published in the previous numbers of this *Journal* [Ramiah, 1933], elaborate presentation of data on inheritance of earliness in rices in India is not easily available, due firstly to the paucity of presentable data, and secondly to their being scattered in different departmental reports and bulletins which fail to command the attention of workers in India and abroad. This work, which differs in certain respects from Ramiah's work, will, therefore, be of interest to workers in other parts of India and abroad.

Two kinds of crosses were made, *viz.*, (1) Between ordinary open-eared types, (Economic crosses) ; (2) Between open-eared types and enclosed-eared types (*Sathi* crosses).

In the present paper the results of only the former group are presented.

The economic crosses were made, in each case, between an early and a late-ripening type. What we mean by an early or a late-ripening type has already been

explained in an earlier publication [Sethi, Sethi and Mehta, 1936], which besides explaining this point, deals with the relation of flowering to ripening. It has not generally been pointed out that the ripening period (*i.e.*, the interval between flowering and ripening) varies in different varieties. Usually it has been stated that it is constant for all varieties. This is not true of the United Provinces rices.

Literature review

Earliness has been a subject of study in different crops by several workers. These studies have shown that earliness may be inherited in different ways even in the same crop. Usually it has been found that the F_1 is intermediate between the parents, its earliness often being near one or the other parent. The F_2 shows great variation and may or may not show grouping into definite classes. In F_3 and later generations, families with different flowering durations can be isolated, thus indicating definite segregation into different classes of earliness. To mention the work of some of the important workers, the name of Farrer [1898] may be mentioned first as being one of the first in the field. He found earliness to be intermediate between the parents in wheat. Biffen [1905] found earliness dominant in an interspecific cross between an early Polish and a late Rivet wheat. Earlier Mendel had found that the F_1 was intermediate in time of ripening in pea [Bateson, 1909]. Keeble and Pellew [1910] demonstrated a dominance of lateness over earliness in pea, although they found that the F_1 was intermediate and not late like the late parent. They conclude that "the time of flowering, though inherited, is modified in its expression in the zygote by morphological characters ...." . Leake [1911] found in cotton that the F_1 was intermediate between the parents, and the mean of the F_2, which was monomodal, was nearest the late parent. Emerson and East [1913] in a cross between a very early and a very late corn found that the cross produced an F_1 generation strictly intermediate between the parents in duration, F_2 generations with a range of variation from the early parent to, or nearly to, the late parent, and F_3 generations with diverse seasons of blossoming. Caporn [1918] found in an oat cross that the F_1 progeny was intermediate between the parents in ripening. The F_2 showed much variation but in F_3 the variation did not extend so far as that of the parents. Thompson [1918] studied numerous crosses in wheat and found the dominance of lateness in F_1. However, in F_2 the majority of individuals were intermediate, but the distribution was not broken up into groups. The apparent dominance of lateness in F_1 has been ascribed to hybrid vigour. Freeman [1918, 1919] demonstrated a partial dominance of lateness in wheat crosses. Florell [1924] in a Sunset-Marquis wheat cross concluded that earliness was dominant in F_2 giving 3·11 to 0·89 early and late plants, "indicating one allelomorphic pair of factors, with possibly a number of minor modifying factors".

In rice one of the first reported studies in earliness is that carried on by van der Stok [1910]. He found earliness dominant in F_1 and a transgressive segregation

in F_2. Hoshino [1915] found F_1 early, F_2 divided into two groups, a large early group and a small late group. Of 340 F_3 families, five were constant for early habit and four for late habit, while the rest were segregating. On a tri-factorial basis the number of pure breeding families expected would be about ten, five early and five late, which is nearly what was obtained. Hence Hoshino advanced a tri-factorial interpretation to explain the results. Ikeno [1918] reporting the work done on rice by Dr. Kato stated that the F_1 was intermediate in earliness, and the F_2 showed a continuous segregation due to multiple factors. Hector [Evans, 1922] found that the F_2 hybrids of a cross between a high coloured autumn (early) rice and a colourless winter (late) rice segregated into two distinct periods (corresponding approximately to the two parents) separated by an interval of about three weeks during which no flowering took place. The ratio of early to late was about 3 : 1. Nomura and Yamazaki [1925] found the F_1 later than the late parent, and the F_2 showed a grouping into three late to one early plants. The late plants were on an average slightly later and the early plants slightly earlier than the late and early parents, respectively. The authors concluded that the inheritance in the crosses was controlled by three factors, **A**, **B**, and **C**, each of which prolonged the shooting time to a certain extent, **C** being most and **B** least efficacious in this respect. Bhide [1926] found lateness dominant, and in the F_2 of a cross and its reciprocal, the ratio of 2·84 and 2·75 late plants to 1 early respectively. Jones [1928] studied a number of crosses for earliness and found the F_1 behaving very differently in the different cases. It was either earlier than the early parent, or nearer the late parent, or as late as the late parent, or very much later than the late parent. In F_2 the population studied could not be classified with certainty into any one of the simple or modified Mendelian ratios. Transgressive segregation occurred, and the classification of the F_2 on the basis of fluctuation of the maximum temperature during the growth season into a small early and a large late group gave a 1 : 3 ratio. In the F_3 one family bred almost true for early maturity, and one almost true for late maturity. Three families segregated into a ratio of three lates to one early and one family produced plants in a distinct ratio one early to two mid-season to one late. Other families showed no definite segregation. Jones concludes that " the data presented indicate that two or more genetic factors are involved in the production of earliness in the rices studied ". Ramiah [1933] studied several crosses at Coimbatore and found that whereas the inheritance was quite simple in some cases showing a single factor difference between earliness and lateness, it was complicated in other cases and could be explained only under the multiple factor hypothesis. He found earliness generally dominant, but has recorded a single case where earliness was recessive.

Material studied

Seven economic crosses were studied. The results are almost alike, hence the description will be confined to only one cross and only the broadest outline of the results of other crosses will be given.

Cross No. 23 (T. 1 × T. 110)

Type 1 is a long fine-grained, early ripening variety possessing weak stem thereby showing a tendency to lodge.

Type 110 is a coarse round-grained, late ripening variety with stronger stem than T. 1. It is much too late in duration to become very popular with the cultivators. Both the types are among the selected types of the United Provinces rices.

The aim of the cross was to isolate—

(1) Early types, heavier in yield and better in stand than T. 1. T. 1, on account of its long grain breaks easily during hulling, and perhaps a slightly coarser grained type would get hulled better.

(2) Late types, with finer grain than the coarse grained T. 110, and with a slightly shorter duration.

The cross was made first in 1929, and later repeated in 1931. The flowering durations of the two types and the F_1 as observed in 1932 were as follows :

	Days
T. 1	89
T. 110	131
F_1	119

Thus, the parents differ from each other by forty-two days. The F_1 is intermediate but is very much nearer the late parent than the early one, indicating the dominance of lateness.

The F_2 and the parents grown in 1931 gave flowering durations stated in Table I.

TABLE I

Mean flowering durations in F_2 and parents in 1931

Culture	Number of individuals	Mean flowering duration	Coefficient of variation
T. 1	192	88·6	2·45
T. 110	259	132·0	0·54
F_2	865	116·8	10·88

The mean flowering duration of F_2 is again intermediate between the two parents, but very much nearer the late parent. The F_2 flowered in two distinct flushes, one early and other late. Table II gives the frequency distribution of the flowering durations, and Figure 1 gives the corresponding bimodal curve.

TABLE II

Frequency distribution of flowering duration in Types 1 and 110 and in F_2 in 1931

Culture	Flowering Duration																				Total
	82	85	88	91	94	97	100	103	106	109	112	115	118	121	124	127	130	133	136	139	
T. 1	3	22	93	64	10	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	192
T. 110	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	76	183	...	...	259
F_2	5	19	15	38	32	35	24	11	1	1	1	27	128	218	115	114	55	18	4	4	865

The modes of the early and the late groups in F_2 do not coincide with the modes of the respective parents, but show a shift towards the middle, as is apparent from Fig. 1.

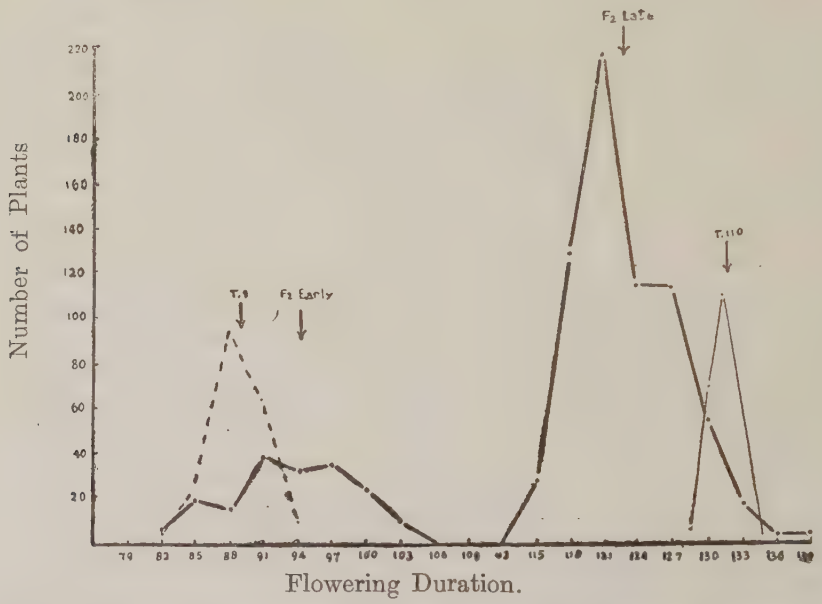


Fig. 1. Frequency distribution of F_2 and parents for flowering duration.

The early segregates hardly transgress beyond the parental limit on the early side, but a majority of them occupy a position later than the mean of the early parent. Similarly in the late segregates the transgression beyond the late extreme is very limited, but the majority of the segregates are earlier than the late parent. The various mean durations are indicated by arrows in Fig. 1 and are given along with their standard errors below.

T. 1	$88{\cdot}6 \pm 0{\cdot}1567$
T. 110	$132{\cdot}0 \pm 0{\cdot}0443$
Early segregates	$93{\cdot}8 \pm 0{\cdot}4166$
Late segregates	$122{\cdot}9 \pm 0.1816$

The difference between the mean duration of T. 1 and of the early F_2 segregates is 5·2 days, and the corresponding difference for the late parent and the late segregates is 9·1 days. These differences are statistically significant as indicated by the high values of $\frac{\text{difference in means.}}{\text{its S. E.}}$

T. 1 and early segregates :

$$\text{Thus ratio} = \frac{5\cdot2}{\sqrt{\cdot1567^2+0\cdot4166^2}} = 11\cdot68$$

T. 110 and late segregates :

$$\text{Thus ratio} = \frac{9\cdot1}{\sqrt{0\cdot0443^2+0\cdot1816^2}} = 48\cdot72$$

Thus there has been a definite 'shift' in the mean durations of the two phenotypes.

Table II as well as Fig. 1 show the dominance of lateness in the F_2. The frequencies are .

	Early	Late	Total
Observed	182	683	865
Calculated on 1 : 3 basis	216·25	648·75	
Deviation	34·25		
$\frac{\text{Deviation}}{\text{Standard Error}}$	$\frac{34\cdot25}{12\cdot74}=2\cdot69$		

The frequencies suggest a 3:1 ratio of late and early plants, although the deviation from expectation is greater than would be caused by chance. However, the F_3 and the subsequent generations, as will be shown later, showed the split into a simple 3:1 ratio, and the deviations were always within the limits of random sampling.

F_3 Generation.—The F_3 generation consisted of 173 families in this cross. The dominance of lateness was confirmed in this generation. Out of the 173 F_2 parents 46 were from the early group and 127 from the late group. The F_3 families from the former all gave only early plants. Of the lates 67 families gave only late plants and 60 families segregated into earlies and lates. The totals from these segregating families and the corresponding figures expected on a 3 : 1 basis are as follows :

	Lates	Earlies	Total
Observed	5,164	1,650	6,814
Calculated	5,110·5	1,703·5	
Deviation	53·5		
S. E.	35·74		
$\frac{\text{Deviation}}{\text{S. E.}}$	=1·50		

The figures are within the range of expectation.

On a 3 : 1 basis it would be expected that out of the 127 late F_2 plants, about two-thirds (*i.e.*, eighty-five) would segregate in the F_3, and the one-third (*i.e.*, forty-two) would give only late plants. Actually the numbers of segregating and pure* late families are 60 and 67, respectively. This wide departure from the expected result will be referred to later and an explanation given.

The F_3 plants of each family were individually noted for flowering duration. The plants were properly numbered in the field with tags and the date of flowering of each plant was noted separately. The data of a few of the representative families of each of the three groups (*viz.*, pure early, pure late and the segregating groups) are summarised in Table III.

TABLE III

Segregation in some of the F_3 families of Cross T. 1 × T. 110 for flowering.

Nature of F_2 parents	Segregation in F_3	F_3 Family No.	F_2 Duration	F_3 Flowering			Segregating Families		Total No. of Plants	Percentage of early plants
				Range	Period	Mean Duration	Earlies	Lates		
Early .	Pure early	18	90	78—94	17	84	...	...	121	...
,,	,,	52	91	78—94	17	90	...	...	112	...
,,	,,	114	102	84—94	11	90	...	...	109	...
,,	,,	150	88	78—94	17	81	...	...	94	...
,,	,,	242	85	78—91	14	86	...	...	105	...
,,	,,	255	90	78—100	23	90	...	...	115	...
,,	,,	263	97	78—103	26	89	...	...	115	...
,,	,,	320	87	81—91	11	83	...	...	115	...
,,	,,	333	91	84—97	14	88	...	...	116	...
,,	,,	336	96	84—103	20	92	...	...	103	...
,,	,,	404	90	78—106	29	90	...	...	107	...
,,	,,	433	98	81—112	32	93	...	...	90	...
,,	,,	486	98	81—91	11	90	...	...	115	...
,,	,,	546	87	81—91	11	85	...	...	114	...
,,	,,	583	87	78—106	29	87	...	...	128	...
,,	,,	869	93	81—91	11	87	...	...	118	...
Late .	Segregating.	12	126	...	...	...	25	88	113	22·1
,,	,,	61	121	...	...	...	28	74	102	27·5
,,	,,	62	123	...	...	...	31	87	118	26·3
,,	,,	187	120	...	...	...	29	69	98	29·6

*The term pure is used here not in the sense of genetic purity (homozygosity), but only to distinguish F_3 families which gave only late or only early plants from those which threw both types of plants.

TABLE III—*contd.*

Nature of F_2 parents	Segregation in F_2	F_3 Family No.	F_3 Duration	F_3 Flowering			Segregating Families		Total No. of Plants	Percentage of early plants
				Range	Period	Mean Duration	Earlies	Lates		
Late	Segregating.	216	125	...	...	...	43	99	142	30·3
,,	,,	256	121	...	...	...	29	86	115	25·2
,,	,,	316	119	...	...	...	37	79	116	31·9
,,	,,	346	118	...	...	...	27	90	117	23·1
,,	,,	377	121	...	...	...	23	89	126	20·5
,,	,,	398	123	...	...	...	30	87	117	25·6
,,	,,	494	121	...	...	...	23	103	161	18·2
,,	,,	516	122	...	...	...	17	92	109	15·6
,,	,,	527	127	...	...	...	36	78	114	31·6
,,	,,	610	126	...	...	...	33	85	118	28·0
,,	,,	670	120	...	...	...	29	88	117	24·8
,,	,,	747	123	...	...	...	17	99	116	14·7
,,	,,	806	121	...	...	...	19	99	118	16·1
,,	,,	847	117	...	...	...	26	87	113	23·0
,,	Pure late	2	130	129—139	11	133	...	...	93	...
,,	,,	21	130	123—136	14	129	...	...	116	...
,,	,,	27	134	126—142	17	135	...	...	93	...
,,	,,	46	123	117—142	26	124	...	...	115	...
,,	,,	66	130	129—133	5	132	...	...	113	...
,,	,,	121	128	120—130	11	125	...	...	115	...
,,	,,	151	121	117—130	14	123	...	...	115	...
,,	,,	179	128	129—148	20	133	...	...	112	...
,,	,,	219	129	129—136	8	133	...	...	111	...
,,	,,	244	121	114—124	11	119	...	...	114	...
,,	,,	334	127	129—139	11	134	...	...	115	...
,,	,,	351	132	129—148	20	140	...	...	116	...
,,	,,	373	126	120—136	17	127	...	...	95	...
,,	,,	397	129	129—136	8	136	...	...	108	...
,,	,,	485	126	114—133	20	124	...	...	120	...
,,	,,	561	127	123—133	11	127	...	...	118	...
,,	,,	895	127	126—133	8	130	...	...	103	...

The segregation into early and late plants was, in every case, very definite and clear-cut, the interval between the upper extreme of early group and the lower extreme of late group being in most families, well over a week. Intervals of two or

three weeks were common. In fact in many of the families some of the early segregates were almost ripe before the late ones started flowering. The classification of plants into earlies and lates in the segregating families was thus very easy, the rather long period of lull leaving no element of doubt regarding the accuracy of the classification.

The interval between the beginning and the finish of flowering in a culture and referred to as flowering period in Table III (Column 6) gives a true picture of the homozygosity of a family. Those which had flowering periods greater than those of the pure lines may be called heterozygous. The pure lines have been observed to take usually from seven to ten days to complete the flowering, though sometimes due to climatic or soil factors the period may be extended to fourteen days or even more. A period of thirteen days or less should be taken as an index of homozygosity, as the observations with pure lines as well as homozygous-looking hybrid families would lead us to assume. On this basis the number of homozygous families was found to be only twenty-three out of a total of 172, *i.e.*, 13·4 per cent of the whole ; of the forty-six early families only five were homozygous, *i.e.*, 10·9 per cent only. It will be shown later how the percentage of homozygous families increased rapidly from one generation to the next.

Relation between F_2 and F_3 durations

F_2-F_3 correlations.—An attempt was made to find out how far the variations observed in the F_2 generations were reproduced in F_3 ; in other words, it was desired to know how far the variation observed in F_2 was genetic. Information on such a problem is best given by the study of correlation between the two generations. Therefore, coefficients of correlation were studied between the F_2 flowering durations and the corresponding F_3 mean durations for both early and late families. Fig. 2 illustrates the correlation which exists between the two generations. In Fig. 2 each dot represents a family, its position indicating the mean value of the family and the duration of its F_2 parent. The arrangement of the dots indicates the existence of positive correlations in the early as well as the late families. The two coefficients and their standard errors are $+ 0{\cdot}4860 \pm 0{\cdot}114$ and $+0{\cdot}9254 \pm 0{\cdot}018$ for the early and late groups, respectively. The number of paired observations was forty-six in the case of the early families and sixty-six in the case of the late families. Reading the significance of the observed correlations from Table V A of Fisher [1932], we find that for $n=40$ or 60, these values show that P is less than 0·01 ; therefore, the correlations are definitely significant. They thus indicate the fact that the variation observed in F_2 was, in a great measure genetic. The wideness of space between the early and the late groups in Fig. 2 shows the difference in time of flowering in early and late families and recalls a similar wide difference existing in the parents themselves.

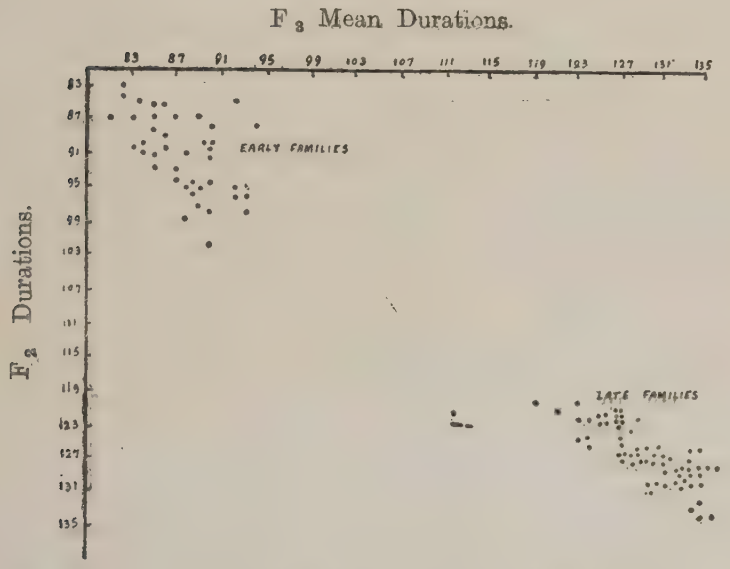


Fig. 2. Correlation between F_2 duration and F_3 mean durations in early and late families.

Fig. 2 is a very apposite illustration of parent-progeny correlation. Mention has been made of the inheritance of F_2 variation in F_3 in rice by other workers in India, but as to the intensity of the relation between the two generations, adequate data have not been presented so far. The magnitude of the work necessary for collecting such data is great and may account for the deficiency of such an information. The data given above seek to make up for this deficiency.

Relation between F_2 duration and F_3 behaviour

It has already been stated that the early F_2 segregates gave only early plants in F_3. Of the late segregates those that segregated into earlies and lates in F_3 flowered, on the whole, slightly earlier in F_2 than those which gave only late plants. In other words, the impure lates were, on the whole, earlier than the pure lates. This difference, though definite, is not clear-cut, because the ranges within which these two types of F_2 lates vary overlap each other considerably as will be seen from Table IV prepared from figures given in column 4 of Table III.

TABLE IV

Distribution of flowering duration of the selected F_2 late plants

Number of F_2 parents	Flowering duration in days																			Mean flowering duration	S. E. of Mean	Mean difference
	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134			
Impure lates.	2	3	2	3	8	15	10	10	1	1	4	3	1	1						121·72	0·369	5·17
Pure Lates						2	1	14	2	3	3	7	10	10	9	..	2	1	2	126·90	0·387	

The difference between the two groups, *viz.*, 5·17 days, is statistically significant, being about ten times the standard error, as shown below :—

$$\frac{\text{Difference}}{\text{S. E. of difference}} = \frac{5{\cdot}17}{\sqrt{0{\cdot}369^2 + 0{\cdot}387^2}} = 9{\cdot}667$$

This establishes the fact that the impure lates are, on the whole, earlier than the pure lates. The wide overlapping of the flowering duration figures in the two cases will be explained later.

How does the above relation between the constitution of the late F_2 hybrids and their durations affect the flowering data of the F_3 generation ? On a little thought it will become evident that such a relation will affect the flowering periods of the late hybrids of pure late and the segregating families in the following way. The late plants of the segregating families will be of two kinds, *viz.*, impure lates and pure lates. Now, since in a family the former tend to give shorter flowering durations than the latter, the result will be an extension of the flowering period of the late plants in the family. On the other hand, the flowering periods of the pure late families will be shorter as these families do not possess ' impure ' plants with a tendency towards shorter flowering duration. That this actually happened in F_3 was clear from a study of the various families as shown in Table V. It gives a comparison of the flowering periods of (1) the late plants from segregating families and (2) the late plants from ' pure ' late families.

TABLE V

Comparison of flowering periods of late plants from segregating and ' pure ' late families

Nature of F_3 families	Flowering period in days										No. of families	Mean flowering period	Mean difference
	5	8	11	14	17	20	23	26	29	32			
'Segregating'	..	1	..	6	10	21	13	7	2	..	60	20·35	5·12
' Pure '	2	4	14	16	15	10	2	2	..	1	66	15·23	

It will be seen that the mean flowering period of the ' segregating ' families is greater (20·35) days than that of the ' pure ' late families (15·23 days). The mean difference, *viz.*, 5·12 days is statistically significant (about 19·45 times its standard error) which is very high.

An explanation may now be given of the wide departure from expected numbers of the segregating and pure late families. It was stated on page 12 that the two kinds of families were 60 and 67 in number, respectively, although on a 3 : 1 basis the numbers ought to have been 85 and 42. The explanation is supplied by the fact given above, *viz.*, that the impure late plants have shorter flowering durations than pure late plants. The mean flowering duration of the late F_2 plants which were selected for the F_3 generation was greater than that of the unselected F_2 population of late plants. That means that the selected F_2 plants were in a greater number of cases ' pure ' than would have been the case if the selection were quite random. The difference in the flowering durations of the selected and unselected F_2 late plants is shown in Table VI.

TABLE VI

Frequency distribution of unselected and selected late F_2 plants

F_2 plants	Flowering duration in days									Total	Mean duration
	115	118	121	124	127	130	133	136	139		
Unselected lates .	27	128	218	115	114	55	18	4	4	683	122·94
Selected lates . .	2	8	32	31	28	20	5	..	..	126	126·69

The mean difference in Table VI is quite significant. The mean duration of the selected late plants is almost the same as that of the ' pure ' late plants given in Table IV, which is 126·90. The bias given to the selection whereby it included a greater number of pure late plants than would have occurred if chance alone operated explains why in the F_3 there was a preponderance of ' pure ' late families.

The comparative precocity of the ' impure ' late plants is of some practical significance. One of the aims of the cross was to evolve late types which were earlier than the late parent. Now, since the ' impure ' late plants have a tendency to flower earlier, selection of the earlier plants from ' segregating ' families in the F_3 or later generations would almost always result in segregation into early and late plants in the next generation. Hence, during the selections this fact had to be borne in mind, and greater importance was attached to the earlier plants of the 'pure ' late families than to those from ' segregating ' families.

F_4 generation.—Fifty-two early F_3 plants and sixty-one late F_3 plants were selected for raising the F_4 generation. The early plants again gave families consisting of early plants only. The flowering periods of the families were, however,

shorter than those of the F_3 families. The average for the fifty-two F_4 families was 15·50 days, while the average for the F_3 families from which the parents for these F_4 families came was 18·96 days—a difference of 3·46 days. An examination of the figures shows that this difference is due both to an increased number of pure (homozygous) families in F_4 as well as to the reduction of flowering periods of impure (heterozygous) families.

Of sixty-one late selections, thirty-six gave only late plants in F_4, while twenty-five segregated into late and early plants. The total frequencies of the latter are :—

	Lates	Earlies	Total
Observed	964	350	1,314
Expected on 3 :1 basis	985·5	328·5	
Deviation . 21·5			
S. E. . . 15·7			
$\frac{\text{Deviation}}{\text{S. E.}}$ =1·369			

i.e., the frequencies are according to expectation.

The number of homozygous families had increased considerably. For example, of the fifty-two early F_4 families, seventeen had flowering periods of thirteen days or less, *i.e.*, they were pure for flowering. That comes to 32·7 per cent of the total number of early families as against 10·9 per cent of early families in F_3 (page 1254), *i.e.*, an increase of about 300 per cent.

In the F_4 stage families with very narrow range of flowering as well as with wide range were obtained. Segregation had, besides, produced families with distinctly different mean flowering durations. A few of the families are illustrated in Fig. 3 which shows the flowering distribution of four early F_4 families, *viz.*, 70-66, 220-3, 14-45 and 512-91, the last of which shows a narrow range and is pure while the first one is distinctly impure. The other two are showing shorter ranges than family 70-66 but are impure.

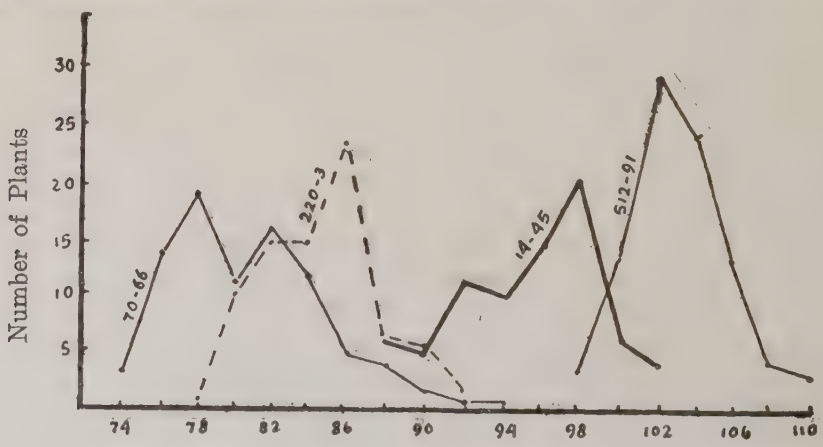


Fig. 3. Four F_4 early families with different mean durations.

F_5 generation.—In this generation there was a further increase in homozygosity. Out of thirteen F_5 families derived from early F_4 families, six were homozygous for flowering, showing ranges of seven to ten days while one with a range of thirteen days was of doubtful homozygosity. The rest possessed flowering periods of fifteen to seventeen days. The mean period for these thirteen F_5 families was 12·0 days, compared to 15·1 days, the mean flowering period of the corresponding F_4 families.

Genetics of the crosses

The foregoing facts can be explained by the following scheme of inheritance. The early type is assumed to have the constitution **aaBBcc** and the late type **AAbbCC**. **C** is the factor for lateness which completely dominates over **A**, a factor for earliness present in the late type. **B** is another factor for earliness present in the early types. This is also recessive to **C** but not so completely as **A**, and gives with **C** plants slightly earlier than the late parent. The cross can be represented thus :

	T. 1		T. 110
	aaBBcc		**AAbbCC**
F_1	.....	**AaBbCc**	
F_2	27	**A B C**	Late
	9	**A B c**	Early
	9	**A b C**	Late
	9	**a B C**	Late
	3	**A b c**	Early
	3	**a B c**	Early
	3	**a b C**	Late
	1	**a b c**	Early

Thus lates : earlies are 48 : 16, or 3 : 1. F_1 is slightly earlier than T. 110, because of the presence of **B**. Similarly in F_2 the majority of lates possess the factor **B**, *viz.* 27 **A B C** and 9 **a B C**, and are consequently slightly earlier than T. 110. The 'shift' in the late segregates towards the middle can thus be accounted for. Similarly the shift in the early segregates can be explained if we assume that the factor **A** for earliness causes a slightly delayed earliness than that of T. 1, both alone and in the presence of **B**. Thus in the scheme out of the sixteen earlies, twelve possess the factor **A** and are, therefore, later than T. 1.

Before explaining the data on the basis of this theory let us first analyse the behaviour of the different genotypes.

The twenty-seven different genotypes, consisting of sixty-four F_2 individuals will breed in several different ways. Classifying them broadly into three divisions,

viz. (*i*) those which give only late plants, (*ii*) those which give early as well as late plants (*iii*) those which give only early plants in F_3, they can be arranged as below :

(i) Genotypes which give only late plants in F_3	(ii) Genotypes which segregate in F_3 into early and late plants	(iii) Genotypes which give only early plants in F_3
1. (a) 1 **AABBCC**	1 (b) 2 **AABBCc**	2. (a) 1 **AABBcc**
1. (c) 2 **AABbCC**	1. (e) 4 **AABbCc**	2. (b) 2 **AABbcc**
1. (d) 2 **AaBBCC**	1. (f) 4 **AaBBCc**	2. (c) 2 **AaBBcc**
1. (g) 4 **AaBbCC**	1. (h) 8 **AaBbCc**	2. (d) 4 **AaBbcc**
3. (a) 1 **AAbbCC**	3. (b) 2 **AAbbCc**	5. (a) 1 **AAbbcc**
3. (c) 2 **AabbCC**	3. (d) 4 **AabbCc**	5. (b) 2 **Aabbcc**
4. (a) 1 **aaBBCC**	4. (b) 2 **aaBBCc**	6. (a) 1 **aaBBcc**
4. (c) 2 **aaBbCC**	4. (d) 4 **aaBbCc**	6. (b) 2 **aaBbcc**
7. (a) 1 **aabbCC**	7. (b) 2 **aabbCc**	8. 1 **aabbcc**
= 16 individuals	= 32 individuals	= 16 individuals

Thus about twenty-five per cent of the F_2 plants should give only late plants in F_3, and fifty per cent should segregate in F_3. This relation was not realized in the F_3 and the reason has already been given on page 1257, *viz.* that the selection of F_2 plants was not random, for it contained a greater number of ' pure ' late plants, than would happen if chance alone operated. As a proof it was stated that the mean flowering duration of ' pure ' late F_2 plants was greater than that of the ' impure ' late plants, and that the selected plants had a flowering duration almost identical with that of the former. The shorter flowering duration of ' impure ' late plants is due to the fact that they comprise genotypes which have only one dose of the factor **C**, besides most of them possessing the factor **B** [column (ii) of preceding statement]. The presence of the **B** factor in the genotypes consisting of pure late plants [column (i) in the preceding statement] also explains the wide overlapping in the flowering duration—figures of the two types of late plants, *viz.* the 'pure' and 'impure' lates,—a fact already stated (page 1256). For, as stated on page 1259, **B** is a factor which gives the late plants a shorter flowering duration because of its incomplete recessiveness to the factor **C**. Now, six of the genotypes of the ' pure ' late group contain the

factor **B**, hence they have flowering durations nearly as short as that of the ' impure ' lates. On this assumption we should expect, in F_3 or later generations, true breeding late families with flowering durations appreciably shorter than that of T. 110. Such families will apparently have the genetic constitution **AABBCC** or **aaBBCC**. In Table III (page 1253), families 121, 244, 561, etc. belong to this group since their mean durations are, respectively, 125, 119 and 127 days and their flowering periods short enough to mark the families as pure. Such families fulfil one of the important aims for which the cross was made, *viz.* evolution of late types with durations shorter than that of T. 110.

Although the term ' pure ' has been generally used for individuals giving only early or late plants, it should not be confused with homozygosity. Many of these so called ' pure ' plants were heterozygous. Taking the late families first, it is clear that plants with a constitution, say, **AABbCC**, will give only late plants, but they will be of two different kinds, one having the duration of F_1 (*i.e.*, earlier than T. 110) and the other having the duration of T. 110. This segregation will consequently increase the flowering period of the family appreciably. Similarly in the case of the early families, those containing plants of the constitution **AAbbcc** or **AABBcc** will be later than the parent although pure in the sense that they consist of homozygous plants. On the other hand families coming from plants of the constitution **AaBBcc** or **AaBbcc** will consist of plants of different kinds some containing the factor **A** and some without this factor, thus being of different durations. Such families are, in the real sense of the term, splitting.

The triple recessive hybrids :—Although in the above cross an early type (T. 1) was crossed with a late one (T. 110) some of the segregates in F_3, F_4 and F_5 were earlier than the early parent. In the scheme of inheritance advanced above this earliness of the hybrids can be explained only if we assume that they are the triple recessive hybrids. Since the selections in the F_2 and the F_3 generations were mainly guided by economic considerations and since some of the earliest plants were very poor in promise they were not included among the selections, and the fact of the extra earliness of the triple recessives could not be very well ascertained at first. The only evidence forthcoming was that certain plants in the F_3, F_4 and F_5 generations flowered earlier than the T. 1 plants. This could only happen if their earliness could be ascribed to the absence of all the three factors **A**, **B** and **C**. If this were really so, and if corresponding selections were made in F_2, we should have got at least one or two pure early families, showing a duration shorter than that of T. 1. Fortunately a duplicate cross had been made in 1931 from which an F_2 was grown in 1933. Selected plants from this were used for raising an F_3, the study of which has amply proved the above view. A part of the data is given in Table VII.

TABLE

Frequency distribution of flowering duration

Flowering

Generation	Year	Culture No.	75 76	77 78	79 80	81 82	83 84	85 86	87 88	89 90	91 92	93 94	95 96	97 98	99 100	101 102	103 104	105 106
P_0 .	1933	T. 1 . .						15	40	25	7	7						
P_0 .	,,	T. 110 .																
F_2 .	,,	F_2 . .				1	2	1	9	26	37	43	39	15	7	3	5	1
P_0 .	1934	T. 1 . .					5	14	52	30	5	1						
P_0 .	,,	T. 110 .																
F_3 .	,,	39				2	5	24	34	27	21	4						
,, .	,,	46			3	13	8	29	41	17	10	1						
,, .	,,	53	2	19	44	33	8	5	5									
,, .	,,	57				2	2	10	13	36	28	19	3	2		1		
,, .	,,	77		3	36	34	12	24	4	3								
,, .	,,	139				2	2	8	23	38	31	7	4					
,, .	,,	196										1		2	4	9	21	23
,, .	,,	245					1		10	14	18	22	4	14	2	3	6	4
,, .	,,	448	7	31	58	14	7	2										
,, .	,,	496			1	6	6	21	49	18	12	1						
,, .	,,	141					6	6	10	1								
,, .	,,	201				1	1		11		4		1	1				
,, .	,,	253		1	1	2		1	9		9	1					1	
,, .	,,	512				1		1	7	2	6	5	4	3	1	3	3	
,, .	,,	590						2	5	2	3	6	4	2		1	3	
,, .	,,	611				1	5	6	9	4	4	2	3					
,, .	,,	466																
,, .	,,	519																

VII

in parental, F_2 and F_3 generations

Duration

107 108	109 110	111 112	113 114	115 116	117 118	119 120	121 122	123 124	125 126	127 128	129 130	131 132	133 134	135 136	137 138	139 140	141 142	143 144	145 146	147 148	149 150	151 152
														6	29	34	10					
		1	1	8	19	73	84	64	46	18	99	30	26	19	13	5	3	1				
																1	3	13	93			
15	18	5																				
4	3																					
		1	2	37	12	13	1	8	2	7	3	1										
				1	3	11	3	11	7	9	8	1	5	5	2	5	7	4	6			
					3	7		8	15	12	6	3	3	4	7	3	3	6	4	44	1	
							2		1		2	6	12	21	13	16	5	1	3		1	
									7	9	18	17	12	9	6	7	3		3			
								4	7	9	16	6	11	8	5	8			2			
										9	13	14	17	23	8	12	5	5	4			
																4	10	19	35	4	10	4

In Table VII, some of the F_3 families bred from F_2 plants of different genotypic constitutions are shown. Apparently F_3 families, No. 53 and No. 448, are from the triple recessive hybrids of constitution **aabbcc** because these families are earlier than Type 1. Family 466 is from an F_2 plant of constitution **AABBCC** and consists only of late plants, most of them earlier than Type 110. Family 519 is from a plant of constitution **AAbbCC** or **AabbCC** and gives a duration more or less like that of T. 110. Of the segregating families, family 611 must be from a plant of constitution **AaBBCc** because the early segregates have durations of T. 1 as well as longer durations and the late segregates are mostly earlier than T. 110. This fits in with the conditions demanded by the theory advanced. Similarly family 253 must have come from a plant of constitution **AabbCc**.

The explanation of the genetics of the cross fits in satisfactorily with the facts observed. It should, however, be noted that the phenotypic classification of the hybrids in F_2 and later generations is not as simple as would be expected on a tri-hybrid basis, because the flowering duration is a character which is not characterised by a clear-cut segregation usual with qualitative characters. The fluctuation shown by the character causes the different phenotypes to merge into each other, thus making it difficult to classify them clearly. Yet the genetical behaviour of the cross is such as to admit of the action of only three important factors in spite of the fluctuations present. That the three factors do not represent the complete picture of the cross is evidenced by the study of later generations. The minute differences between families and the very gradual narrowing of flowering periods in successive generations, are proofs that besides the three major factors already described there are several minor factors deciding the heredity in the cross. The tri-hybrid explanation advanced has, therefore, to be taken with this reservation.

Other economic crosses.—In essential features the data from other crosses were similar to those for the cross already described. In every case the F_2 and F_3 generations were studied in detail, record for individual plants being kept separately. In F_4 and F_5 generations, the purity or otherwise of the different families was noted by repeated countings of the flowered plants on alternate days. On account of the similarity of the results with those already described in detail for cross No. 23 (T. 1 $\times$ T. 110) it will be unnecessary to give the details here. Only the broad outlines of the results are presented.

F_2 generations.—They showed clear segregation into early and late plants. Unlike cross 23 described above the other crosses gave good fits of 3 late : 1 early plants. The population varied from 600 to 900 plants. The crosses studied were :

Cross No.	Parents
21	T. 1 and T. 100
24	T. 3 and T. 5
25	T. 1 and T. 26
27	T. 12 and T. 26

Types 5, 26 and 100 were the late parents.

F_3 generations.—The early F_2 plants bred only early plants in F_3. The late F_2 plants either bred 'pure' or segregated into earlies and lates. The number of F_2 plants selected and their behaviour in F_3 are given in Table VIII.

TABLE VIII

F_2 plants selected and their behaviour in F_3

Cross No.	No. of F_2 families	Nature of F_3 parents	Segregation	Frequencies	
				Calculated	Observed
22	221	55 Early . 166 late . .	'pure' early 'pure' late segregating into 3 lates : 1 early	55 55 111	55 64 102
25	209	36 early . 173 late .	'pure' early 'pure' late segregating into 3 lates : 1 early	36 58 115	36 73 100
27	153	39 early . 114 late .	'pure' early 'pure' late segregating into 3 lates : 1 early	39 38 76	39 68 46

The frequencies of the early and late classes are given in Table IX.

TABLE IX

Early and late plants from segregating F_3 families

Cross No.	No. of families	Observed or calculated	Frequencies		Deviation	Standard Error	Dev./S. E.
			Early	Late			
22	102	Observed	2985	8630	81·25	46·66	1·74
		Calculated	2903·75	8711·25			
25	100	Observed	2746	8048			
		Calculated	2698·5	8095·5	47·5	44·98	1·06
27	46	Observed	1210	3674			
		Calculated	1221	3663	11	30·26	0·36

It will be seen that the deviation in all the cases is within range of expectation.

The percentage of the early plants on the total in each family was separately worked out in the different crosses. It was seen that the percentages varied considerably and were, in a majority of cases, between twenty and thirty. Thus in

crosses 22, 23, 25 and 27, the number of families which had percentages of early plants between twenty and thirty was 205 out of 308. The mean percentages in the four crosses were 25·8, 24·2, 25·4 and 24·9, respectively—figures very near 25·0, the required theoretical figure.

F_4 generations.—The early F_3 plants again bred true to early habit in F_4. There were 402 early families in the crosses. The late F_3 plants which segregated in F_4 always threw early and late plants in 1 : 3 ratio. The frequencies and deviations are given in Table X. The number of 'pure' late families was 249 excluding the 36 families of cross No. 23, already mentioned.

TABLE X

Frequencies and deviations from calculated figures of early and late plants in segregating F_4 families

Cross No.	No. of families	Observed or calculated	Frequencies. Early	Frequencies. Late	Deviation	Standard Error	Dev./S. E.
21	63	Observed	1047	2958			
		Calculated	1001·25	3003·75	45·75	27·40	1·67
22	41	Observed	648	1918			
		Calculated	641·5	1924·5	6·5	21·93	0·30
25	34	Observed	660	1845			
		Calculated	626·5	1878·75	33·75	21·66	1·56
27	22	Observed	458	1470			
		Calculated	482	1446	24	19·01	1·26

It will be seen that the ratio of early and late plants shows good fit in every case. The 'pure' families had become homozygous to a considerable extent as already described in cross No. 23.

F_5 generations.—There was a total of 132 early families in all the crosses, 35 families segregated into early and late plants, and 65 families gave only late plants. The frequencies of early and late plants from the 35 segregating families are as follows:

	Early plants	Late plants
Observed	951	2915
Calculated	966·5	2899·5
Deviation	15·5	

$$\text{Deviation/S. E.} = \frac{15{\cdot}5}{26{\cdot}7} = 0{\cdot}6 \text{ (nearly)}$$

CORRELATION BETWEEN FLOWERING AND SOME OTHER CHARACTERS

A few interesting correlations between flowering duration and other characters may now be described.

1. Flowering and yield.—Yield is a very important consideration in crop improvement. Since, however, it can not be judged with any degree of completeness in the earlier stages of breeding work the utmost that a worker can do is to exploit its correlations with the more easily recognisable features of the crop and thereby be guided in his selections. Securing a marked earliness alone would not be an achievement unless it were accompanied by good yield. The importance of the two characters, *viz.*, earliness and yield is obvious. Until the two characters are studied in relation to each other selection is likely to be arbitrary. In the collection of pure lines at the Rice Research Station, Nagina, it has been observed that some of the late types appear to be of remarkable yielding capacities. There are no doubt a few early heavy yielders, but the balance of heaviness seems to be inclined towards the late types. No correlation between flowering duration and yield has been studied in the pure lines. In the crosses, however, it was suspected that a positive correlation might be present in which case it would become difficult to combine earliness with very high yields in the hybrid varieties. It was, therefore, felt that a knowledge of the correlations would enable us to judge the possibility of combining the two characteristics, and to base our selections on surer foundations. The results are given below :—

In 1933 an F_2 generation of cross No. 23 (T. 1 × T. 110) was harvested, grain from individual plants was threshed separately, and after the grain was thoroughly dried in the sun the weights were taken in grammes. The correlation between yield of individual plants and the flowering duration was calculated separately in the early and the late groups. The values of r and their standard errors were $+0{\cdot}0268 \pm 0{\cdot}0808$ and $+0{\cdot}0348 \pm 0{\cdot}0472$, respectively for the two groups. Apparently correlation was absent. The mean yield of the late hybrids was, however, slightly greater than that of the early hybrids, but the difference was not statistically significant. The yield distribution of the hybrids transgressed the parental limits in both the directions, especially toward the higher extreme. The four mean values are given below :

Culture	Mean yield (in grms.)
T. 1	25·89
T. 110	33·89
F_2 Early	45·43
F_2 Late	47·14

The markedly higher figures in the hybrids may be due to hybrid vigour. The mean difference between the parents, *viz.*, 8·0 grms. is statistically significant.

2. Average yield per ear.—One of the factors which determines the yield of crop is the heaviness of individual ears of a plant. An average ear of T. 110 possesses

a very much greater number of spikelets than an ear of T. 1, resulting in a greater weight of threshed grain from each ear. It was resolved to investigate if the relation shown by the parents, *viz.* greater yield per average ear in late plants (T. 110) compared to that of early plants (T. 1), was reproduced in the F_2 hybrids too.

In F_2 the coefficients of correlation between flowering duration and yield per ear were calculated separately for the early and the late hybrids. The two values of r are $+0{\cdot}0457$ and $-0{\cdot}0152$. None of these values is significant. That is, within the same group, the later plants do not give heavier ears. However, the mean yield per ear of the late group is greater than that of the early group, the two means being 3·22 and 2·95 grms., respectively. The difference between the two figures has been found to be statistically significant, the value of 't' being 4·05.

The comparison of hybrids with the parents for the character under consideration is given in Table XI.

TABLE XI

Frequency distribution of one-ear yield in parents and F_2 hybrids of cross T. 1 × T. 110 in 1933

Class centres in grms.	T. 1 (1)	T. 1 (2)	T. 110 (1)	T. 110 (2)	F_2 hybrids	
					Early	Late
0·9	..	..	..	..	1	3
1·1	..	1	..	..	..	3
1·3	..	..	..	..	1	2
1·5	..	..	..	..	1	5
1·7	3	3	..	..	3	11
1·9	2	1	..	1	4	11
2·1	5	16	..	1	9	17
2·3	7	9	2	1	11	23
2·5	13	18	2	2	25	32
2·7	13	14	3	..	15	38
2·9	14	14	7	8	14	41
3·1	9	3	11	5	20	43
3·3	8	1	11	14	16	44
3·5	1	1	8	15	9	45
3·7	..	..	10	11	9	35
3·9	..	..	17	16	11	33
4·1	..	..	13	13	7	19
4·3	..	..	7	7	1	17
4·5	..	..	8	8	..	13
4·7	..	..	7	1	2	9
4·9	..	..	5	..	..	12
5·1	..	..	..	1	..	2
5·3	..	..	..	..	..	3
5·5	..	..	..	..	..	1
5·7	..	..	..	..	..	..
5·9	..	..	..	..	..	1
6·1	..	..	..	..	..	1

It will be seen that the distribution in T. 110 occupies higher classes than that in T. 1. In each type distributions of two cultures are given, one grown on each side of the hybrid lines in the field. The means of the four parent cultures and the two hybrid groups are as follows :

T. 1 (1)	2·6867 grms.
T. 1 (2)	2·4926 „
T. 110 (1)	3·7523 „
T. 110 (2)	3·6635 „
F_2 Early	2·9503 „
F_2 Late	3·2203 „

The mean difference between the early parent and the F_2 early group, and that between the late parent and F_2 late group are statistically significant, the F_2 early and late groups being intermediate between the means of the two parents. This is only a case of ' shift ' in inheritance of the character.

The frequency distributions of the hybrids, besides showing mean values intermediate between the parents, are showing greater ranges of variation than the range occupied by the parents. Thus the hybrid plants show both lighter and heavier ears than the parental extremes. The former may be due to an abundance of sterile spikelets possessed by some of the hybrids and the latter may be due to hybrid vigour.

3. Weight of five ears.—In the above study the average yield per ear was obtained by dividing the plant yield by the number of ears harvested. The inheritance of heaviness was studied by a different method in another F_2 culture of the same cross in 1931. In this case, weight of five ears was taken as a character for study. The parental and F_2 cultures were studied in the same year.

The mean weight, range of variation, and standard error of mean weight are presented in Table XII.

TABLE XII

Mean five-ear weight, range of variation, etc. in parental and F_2 cultures in 1931

Culture	No. of plants	Range of variation grms.	Mean weight grms.	S. E. of mean
T. 1	130	15·5-29·5	23·50	0·1894
T. 110	130	23·5-41·5	34·44	0·2836
F_2 Early	182	5·5-33·5	20·03	0·4338
F_2 Late	683	5·5-51·5	22·54	0·3070

The two F_2 groups, early and late, show variation over a wide range, and show a difference in mean weights which is statistically significant. The coefficients of correlation between the flowering duration and five-ear weight were calculated

separately for early and late hybrids, and are, respectively, —0·1741 and +0·4529. Fisher's Table VA [Fisher, 1932] shows that the former value is not significant, the value of P being above 0·05 ; the latter value is significant, the value of P being less than 0·01.

The distribution of five-ear weights, like the distribution of one-ear yield, was very wide in F_2 and embraced both the extremes of the parents, and even extended beyond. The early plants possessed, on the whole, lighter ears than the late plants. In F_2, F_3 and F_4, certain plants were obtained in the early as well as the late groups which possessed heavier ears than the heaviest-eared plants of the parents. The distributions of parents, F_2 and the selected plants of F_2, F_3 and F_4 are illustrated in Fig. 4 where the barred columns represent early plants and the solid columns, the late plants.

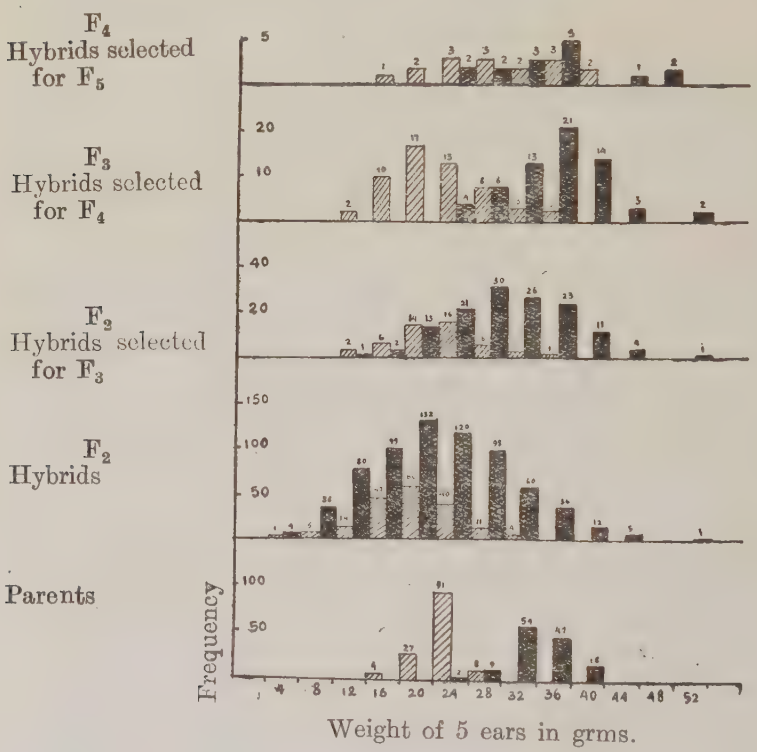


Fig. 4. Weight of five ears in parental, F_2, F_3 and F_4 generations.

4. Flowering and number of tillers.—Tillers were counted in the parents and the F_2 generation in a cross between T. 1 and T. 110 in 1933. Each parent was represented by two cultures in the field, one on each side of the hybrid lines. The range

of variation was greater in the F_2 than in the parents. The averages and their standard errors are given below.

Culture	Mean number of tillers	Standard error
T. 1 (1)	9·95	0·2373
T. 1 (2)	10·66	0·2786
T. 110 (1)	9·13	0·2489
T. 110 (2)	11·68	0·3251
F_2 Early	15·07	0·3418
F_2 Late	14·70	0·2148

The averages for the hybrids are appreciably higher than those for the parents. This may be only an expression of hybrid vigour.

The coefficients of correlation between the flowering durations and the number of tillers were also calculated both in the early as well as the late hybrids. The values of r obtained were, respectively, —0·0546 and —0·0258, thus showing a complete lack of correlation between the two characters. In other words the early plants are as likely to be well tillered as the late plants. Since tillering decides, to a considerable extent, the yield of a plant, the natural corollary of the above fact is that if once good tillering is secured in early cultures (which fact is possible because of the absence of correlation between flowering and tillering) there are reasonable chances of their being good yielders.

Summary

Some crosses between early and late types of rice have been studied for the inheritance of flowering duration and its relation to certain other characters, and the data have been presented in the present paper. The inheritance of flowering duration was thoroughly Mendelian. The main facts were :

1. The F_1 showed dominance of lateness, being only slightly earlier than the late parent.
2. The F_2 distribution covered the parental extremes, and could be divided into two distinct groups of hybrids, an early and a late group in the ratio of 1 : 3 thus indicating a dominance of lateness.
3. The two F_2 means were statistically different from the parental means, the former showing a ' shift ' toward the middle.
4. The segregations in F_3 confirmed the observations made in F_2. The segregation into early and late plants was always in 1 : 3 ratio, wide departures from the ratio being very few.

5. The correlation between the flowering durations of F_2 and F_3 generations was close and positive.

6. There was a definite relation between the flowering durations of late F_2 plants and their genetic constitution (as revealed by their behaviour in F_3), the impure lates being, on the whole, slightly earlier than the pure lates, the difference being statistically significant, although the flowering distributions of the two kinds of late plants showed considerable overlapping.

7. As a result of the relation mentioned in paragraph 6 of the range of flowering of late plants of 'segregating' families becomes greater than that of the late plants of 'pure' families in F_3 and later generations.

8. The number of homozygous families increased rapidly from generation to generation.

9. The genetics of the crosses have been explained on the assumption that three factors, one from the early types and two from the late types, interact in inheritance and cause the segregations observed. The facts mentioned in the preceding paragraphs have been satisfactorily explained by the tri-hybrid scheme of inheritance suggested. The scheme has, however, to be accepted with the reservation that besides these three important factors, there may be minor factors too which decide the inheritance in the cross.

10. Although the yield per plant was higher in the late parent, the F_2 late hybrids were not heavier in yield than the early F_2 hybrids. The coefficients of correlation between flowering and yield in the two groups were insignificant.

11. Yield per ear was greater in the late hybrids than in the early ones, as was the case in the parents.

12. The coefficient of correlation between flowering duration and weight of five ears was insignificant in the early F_2 hybrids, but significant in the late hybrids.

13. The parents differed from each other but slightly in the number of tillers per plant. The F_2 early and late groups possessed significantly greater number of tillers than the parents, but the difference between the two groups was not significant. The coefficients of correlation between flowering duration and tillering were insignificant in the two cases.

REFERENCES

Bateson, W. (1909). 'Mendel's Principles of Heredity,' Cambridge University Press, 1909.

Bhide, R. K. (1926). *Poona Agricultural College Magazine* **1** : 76-85.

Biffen, R. H. (1905). *Jour. Agric. Sc.* **1** : 4-48.

Caporn, A. S. (1918). *Jour. Gen.* **7** : 247-257.

Emerson, R. A. and East, E. M. (1913). *Nebraska Agric. Expt. St. Res. Bul.* **2** : 1-12.

Evans, G. (1922). *Bengal Dept. Agric. Report*, 1921-22 : 138.

Farrer, W. (1898) *Agric. Gaz. New South Wales* **9** : 131-168, 241-260.

Florell, V. H. (1924). *Jour. Agric. Res.* **29** : 7, 336.

Freeman, G. F. (1918). *Jour. Her.* **9** : 211-226.

——————— (1919). *Gen.* **4** : 1-93.

Hoshino, Y. (1915). *Jour. Col. Agric. Tohoku Imp. Univ. Sapporo, Japan*, **6** : 229-288.

Ikeno, S. (1918). A Text Book on Genetics, Ed. 3, Tokyo (In Japanese). Quoted from *Bot. Abs.* **2**, 1919, p. 115.

Jones, J. W. (1928). *Jour. Agric. Res.* **36** : 581-601.

Keeble, F. W. and Pellow, C. (1910). *Jour. Gen.* 1 : 205-272.

Nomura, M. and Yamazaki, R. (1925). *Jap. Jour. Gen.* **3** : 112-130.

Ramiah, K. (1933). *Ind. Jour. Agric. Sc.* **3** : 3, 377-410.

Sethi, R. L., Sethi, B. L. and Mehta, T. R. (1936). *Ind. Jour. Agric. Sci.* **6** : 2, 361-376.

Stock, Van der (1910). Quoted from S. Ikeno (1927). *Bibl. Gen.* **3** : 245-310.

Thompson, W. P. (1918). *Trans. Roy. Soc., Canada*, **3** : 12, 69-87.

MENDELIAN SEGREGATION IN *HIBISCUS SABDARIFFA* L. IN RELATION TO THE AGE OF THE F_1 AT TIME OF FERTILIZATION

BY

R. B. DESHPANDE, M.Ag. (Bom.),

Special Research Assistant to the Imperial Economic Botanist, Imperial Agricultural Research Institute

(Received for publication on the 19th June, 1936)

(With seven text-figures)

CONTENTS.

		Pages
I.	Introduction	1274
II.	Material and method	1275
III.	First series of experiments	1276
IV.	Second series of experiments	1287
V.	Discussion	1290
VI.	Summary and conclusion	1291
VII.	References	1291

I. Introduction

In the course of inheritance studies it is sometimes found that Mendelian ratios in the F_2 generation show a considerable deviation from theory. This is most frequently due to the population examined being insufficiently large. Other possible causes are linkage, lethal factors, or faulty identification of the phenotypes.

Various workers have brought forward evidence of the existence of yet another factor—a seasonal effect on segregation. Christie and Wriedt [1930], working with the domestic pigeon, found a seasonal variation in the segregation of the sex-linked factor for colour intensity. The same workers report that when hybrid Plymouth Rock × Minorka males (heterozygous for the sex-linked factor producing barring) were crossed with black Minorka females, there was a tendency to give an excess of barred offspring at the beginning of the season and an excess of black towards the end of the season. These instances suggest a seasonal variation in the viability or the power of fertilisation of the gametes. In the same material, however, Christie and Wriedt did not find any seasonal effect with regard to the sex-linked factor for piebald pattern, nor was any such effect noted by these workers on the segregation of the character pairs, greenness and yellowness, or tallness and dwarfness in *Pisum sativum*.

Haigh and Lochrie [1929], working with cowpea (*Vigna sinensis*), found a periodic variation in the Mendelian ratio between the dominant axil-spot plants and the recessive albino plants (3 : 1 on theory) in the F_2 progeny contributed by a number of F_1 plants selfed from day to day. They found that in the first-formed flowers there was a strong tendency to produce the recessives in excess, whilst in the progeny from later-produced flowers dominants became increasingly abundant until the ratio of dominants to recessives was the reverse of what was observed initially. This effect appeared to be unconnected with environmental factors such as temperature, humidity, etc., and is attributed by Haigh and Lochrie [1929] to the age of the parent.

If age has any influence on the F_2 segregation, then the stage at which the F_1 plants should be selfed, as also the extent of period for which they should be selfed, are very important points to consider in an inheritance study. It is these considerations which suggested the investigation described in the following pages.

II. Material and method

The plant selected for this investigation was *Hibiscus* (*H. sabdariffa* L.). The following considerations led to the selection of this plant :—

1. It provides sharply contrasting characters of which the mode of inheritance has already been studied.
2. The characters are such as can be studied when the plant is a month old or less. After the observations are over the crop can be ploughed in as a green manure and a winter crop raised in the same field the same year. This consideration is a great advantage in that it makes available the large area which is necessary for such an experiment.
3. Flowers are big and are easily selfed individually.
4. Seed production is high, each fruit normally giving about fifteen to twenty seeds. A maximum of about thirty-five seeds has been harvested from a single capsule.
5. The flowering period is of a fairly long duration.
6. The plant is practically free from insect pests and diseases.

Three Pusa types of *H. sabdariffa* L. were selected as parents of the crosses. These types have been maintained as pure cultures and their genetical constitution already studied [Howard and Howard, 1924]. Two characters, narrowness or broadness of leaf-lobe, and redness or greenness of stem-colour were taken into consideration for the present investigation. Narrow leaf-lobe is found to be dominant to its allelomorph, broad lobe, on a 3 : 1 monohybrid ratio. Red colour in stem in the cross, *New Hibiscus* $\times$ *Albus*, is dominant to green, giving a ratio of 3 reds (various grades and forms) : 1 green in F_2. This character in this cross is,

however, determined by three factors as shown by genetical investigations (unpublished records by the author). In the cross, *New Hibiscus* × *Ruber*, the red stem is dominant to green stem with red patches in the leaf-axil, etc., on a dihybrid basis, but the ratio of the frequency of the former phenotype to the latter is 3 : 1. In this investigation the counts were made on the above basis.

III. First series of experiments

The following crosses were made in the year 1931-32 :—

1. *New Hibiscus* × *Albus*
2. *New Hibiscus* × *Ruber*

New Hibiscus has narrow-lobed leaves and a green stem with red patches in the leaf-axil and just below it. *Albus* and *Ruber* have broad-lobed leaves ; but the former has a green stem and the latter red. The F_1, in both the crosses, had narrow-lobed leaves and red stem.

The seeds of the two crosses were sown the following year (1932-33), and a number of F_1 plants were raised. The spacing and subsequent treatments were kept uniform. Only five F_1 plants from each of the two crosses were kept, the rest being removed. All the ten plants were from seeds which germinated on the same day, and were uniformly vigorous and healthy from the beginning to the end.

The flowering commenced on November 2, 1932, in seven out of the ten F_1 plants and by November 5, all the plants were in flower. Thus, all these plants were also practically uniform as regards their flowering age.

(1) All flowers on each F_1 plant were selfed daily from the commencement of flowering till November 12, 1932, but thereafter with the increasing number of flowers, it was found difficult to self all of them, and hence only a sufficient number was selfed at random, the rest being pulled out.

(2) Selfing was done the evening previous to the opening of the flower by slipping a small wire ring over the conical bud. Rubber solution and " Seccotine " were also tried and found satisfactory.

(3) Each selfed bud was labelled, the label denoting the cross, the plant number, and the date of selfing.

(4) Every morning, at about 8 o'clock, which is the time for the opening of the flowers, the flowers were examined to see if the corolla had slipped out of the ring, in which case the flowers were rejected.

(5) Shedding was observed to take place. The number of flowers shed each day was recorded for each plant.

(6) As the fruits matured they were harvested. The produce of each plant, as also that from each day's selfing, was kept separate.

(7) Selfing was continued till the 25th December, 1932, and thereafter was stopped because of scanty flowering and low setting.

A complete record was kept of the following points :—

(*a*) the number of flowers selfed per day,

(*b*) the number of flowers removed per day,

(*c*) the number of flowers shed per day,

(*d*) the number of fruits harvested per day,

(*e*) the total number of flowers produced by each plant per day, and

(*f*) the date of first and last flowering.

Thus seeds from these F_1 plants selfed on successive days for about fifty to fifty-five days were available.

In the first week of July, 1933, these seeds were sown (dibbled) separately for each F_1 plant and for each day. Unfortunately the germination suffered due to heavy rains immediately after the sowing with the result that out of about 20,000 seeds sown only about 8,000 germinated.

Observations were taken when the plants were three to four weeks old. Even at this early stage the two characters, leaf-lobe and stem-colour, could be correctly classified into the different F_2 phenotypes.

In each of the two crosses, the following constants were calculated for both the characters (leaf-lobe and stem-colour) :—

(1) Ratio of dominants to recessives for each day.

(2) Deviation between the observed and theoretical frequencies of the recessive phenotype.

(3) Three times the Probable Error.

The ratio of dominants to recessives was first calculated for each F_1 plant separately, but as the different plants did not show any great variation in the behaviour for their segregation in F_2, the frequencies of all the F_1 plants of each cross were added up together.

Curves were drawn for each of the three above constants. Temperature and humidity curves for the period of flowering, as well as curves showing the total number of flowers produced per day for each cross, were also constructed. These showed no relation with the daily ratios and are not presented here.

Experimental results

The results of each cross will be dealt with separately.

New Hibiscus × *Albus*

Leaf-lobe.—New Hibiscus has a narrow leaf-lobe and *Albus* has a broad leaf-lobe. The F_1 had a narrow leaf-lobe. In F_2, a ratio of 3 narrow leaf-lobed plants : 1 broad leaf-lobed plant is theoretically expected in the population of each successive day, if age or any environmental factor were not to influence the F_2 segregation. The observed results are shown in the following table :—

TABLE I

Showing the daily frequencies of the two phenotypes, their ratios, total population, deviation between observed and theoretical frequency of the recessive, and 3 P. E.

New Hibiscus × Albus—F_2

Leaf-lobe

Flowering day	Narrow lobe	Broad lobe	Total	Ratio	Deviation	3 P. E.
1	27	7	34	3·86	—1·50	5·10
2	16	9	25	1·78	+2·75	4·38
3	52	15	67	3·46	—1·75	7·17
4	45	15	60	3·00	0·00	6·78
5	7	4	11	1·75	+1·25	2·91
6	94	30	124	3·13	—1·00	9·75
7	51	23	74	2·22	+4·50	7·53
8	75	24	99	3·13	—0·75	8·72
9	70	21	91	3·30	—1·75	8·35
10	224	85	309	2·63	+7·75	15·40
11	58	21	79	2·76	+1·25	7·79
12	87	31	118	2·81	+1·50	9·51
13	149	52	201	2·86	+1·75	12·39
14	133	35	168	3·80	—7·00	11·35
15	93	42	135	2·21	+8·25	10·18
16	101	40	141	2·52	+4·75	10·40
17	69	21	90	3·29	—1·50	8·31
18	120	39	159	3·08	—0·75	11·05
19	199	62	261	3·21	—3·25	14·16
20	119	42	161	2·83	+1·75	11·12
21	163	72	235	2·26	+13·25	13·43
22	116	43	159	2·70	+3·25	11·05
23	93	32	125	2·90	+0·75	9·79
24	80	23	103	3·48	—2·75	8·89
25	114	30	144	3·80	—6·00	10·51
26	84	45	129	1·87	+12·75	9·95
27	93	28	121	3·32	—2·25	9·64
28	69	23	92	3·00	0·00	8·41
29	39	11	50	3·82	—1·50	6·19
30	83	39	122	2·13	+8·50	9·68
31	59	25	84	2·46	+4·00	8·03
32	53	22	75	2·41	+3·25	7·59
33	69	30	99	2·30	+5·25	8·72
34	42	12	54	3·50	—1·50	6·44
35	89	42	131	2·12	+9·25	12·03
36	68	17	85	4·00	—4·25	8·08
37	4	2	6	2·00	+0·50	2·15
38	13	2	15	6·50	—1·75	3·39
39	8	2	10	4·00	—0·50	2·77
40				No setting		
41	6	2	8	3·00	0·00	2·48
42	19	7	26	2·71	+0·50	4·46

TABLE I—*contd.*

Flowering day	Narrow lobe	Broad lobe	Total	Ratio	Deviation	3 P. E.
43	1	1	2	1.00	+0·50	1·24
44	1	0	1	0·00	—0·25	0·88
45			No setting			
46	2	0	2	0·00	—0·50	1·24
47	4	2	6	2·00	+0·50	2·15
48			No setting			
49	5	2	7	2·50	+0·25	3·32
50	8	2	10	4·00	—0·50	2·77
51	9	4	13	2·25	+0·75	3·16
52	21	8	29	2·62	+0·75	4·72
53	43	11	54	3·91	—2·50	6·44
54	43	17	60	2·53	+2·00	6·79

$\chi^2 = 45 \cdot 25.$

$\sqrt{2\chi^2} - \sqrt{2n-1} = 0 \cdot 53.$ The fit is good.

Table 1 clearly shows that :—

(1) the ratio of the dominants to the recessives varies from day to day, but the positive and negative deviations appear fairly at random.

(2) the deviations on all days except one (26th day), *i.e.*, in about ninety-eight per cent cases are within the limits of chance errors and are thus not significant.

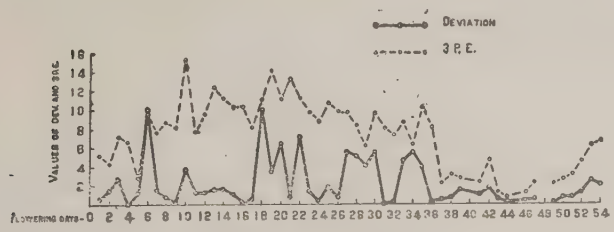


Fig. 1. Leaf-lobe (*New Hibiscus* × *Albus*).

The deviation curve (Fig. 1) will be seen to remain within the 3 P. E. curve all along except at one point, *viz.*, on the 26th, where it cuts the Probable Error curve, indicating a significant deviation in the ratio on that day only.

Thus it may be safely concluded from these results that the age of the F_1 plant or season has no effect on the F_2 segregation for this character (leaf-lobe) in *Hibiscus*.

Each individual F_1 plant showed a good fit to a 3 : 1 ratio when the daily frequencies were added up.

The total phenotypic frequencies in the whole cross were as follows :—

	Narrow-lobed plants	Broad-lobed plants	Total
Total observed	3,290	1,174	4,464
Total expected on 3 : 1 basis	3,348	1,116	4,464
Deviation	58	58	

$$\frac{\text{Dev.}}{\text{P. E.}} = \frac{58}{19{\cdot}34} = 3.$$ The fit is just good.

The " fits " for the populations of all the five F_1 plants taken individually were good.

The " fit " for the frequencies during the whole flowering period was tested by the formula $\sqrt{2\chi^2} - \sqrt{2n-1}$ [Fisher, 1932] and was good as shown at the bottom of Table I.

Stem-colour.—New Hibiscus has a green stem with red patches in the leaf-axil and below it. The stem of *Albus* is purely green. The F_1 had red stem, and in F_2 the ratio of red stem (various grades) to green was as 3 : 1.

Table II and Fig. 2 show that in this case also there is no seasonal or age effect on segregation. The deviations between the observed and expected frequencies were, however, significant only on the 6th day.

TABLE II

Showing the daily frequencies of the two phenotypes, their ratios, total population, deviation between observed and theoretical frequency of the recessive, and 3 P. E.

New Hibiscus × *Albus*—F_2

Stem-colour

Flowering day	Red stem	Green stem	Total	Ratio	Deviation	3 P. E.
1	26	8	34	3·25	—0·50	5·10
2	18	8	26	2·25	+1·50	4·47
3	53	14	67	3·79	—2·75	7·18
4	45	15	60	3·00	0·00	6·78
5	7	4	11	1·75	+1·25	2·91
6	103	21	124	4·91	10·00	9·75
7	57	17	74	3·35	—1·50	7·53
8	75	24	99	3·12	—0·75	8·72
9	67	22	89	3·04	—0·25	8·26
10	228	81	309	2·81	+3·75	15·41
11	58	21	79	2·76	+1·25	7·79
12	88	31	119	2·84	+1·25	9·55

TABLE II—*contd.*

Flowering day	Red stem	Green stem	Total	Ratio	Deviation	3 P. E.
13	153	49	202	3·12	—1·50	12·44
14	129	41	170	3·15	—1·50	11·39
15	101	35	136	2·89	+1·00	10·25
16	106	35	141	3·03	—0·25	10·40
17	68	22	90	3·09	—0·50	8·31
18	110	50	160	2·20	+10·00	11·08
19	193	69	262	2·80	+3·50	14·19
20	115	47	162	3·19	+6·50	11·13
21	177	58	235	3·05	—0·75	13·43
22	112	47	159	2·38	+7·25	11·05
23	95	30	125	3·17	—1·25	9·79
24	77	26	103	2·96	+0·25	8·89
25	107	38	145	2·82	+1·75	10·51
26	96	33	129	2·91	+0·75	9·95
27	97	25	122	3·88	—5·50	9·68
28	74	18	92	4·11	—5·00	8·40
29	43	8	51	5·38	—4·75	6·25
30	97	25	122	3·88	—5·50	9·68
31	63	21	84	3·00	0·00	8·03
32	57	18	73	3·17	—0·25	7·48
33	79	20	99	3·95	—4·75	8·72
34	35	19	54	1·84	+5·50	6·44
35	95	37	132	2·57	+4·00	10·07
36	64	21	85	3·05	—0·25	8·08
37	4	2	6	2·00	+0·50	2·15
38	12	3	15	4·00	—0·75	3·39
39	9	1	10	9·00	—1·50	2·77
40			No setting			
41	5	3	8	1·67	+1·00	2·46
42	22	5	27	4·40	—1·75	4·56
43	1	1	2	1·00	+0·50	1·24
44	1	0	1	0·00	—0·25	0·88
45			No setting			
46	2	0	2	0·00	—0·50	1·24
47	4	2	6	2·00	+0·50	2·15
48			No setting			
49	5	2	7	2·50	+0·25	2·33
50	6	3	9	2·00	+0·75	2·63
51	9	4	13	2·25	+0·75	3·16
52	23	6	29	3·83	—1·25	4·72
53	43	11	54	3·91	—2·50	6·44
54	43	17	60	2·53	+2·00	6·79

Here the deviation, being greater than 3 P. E., is significant.

$$\chi^2 = 32 \cdot 29.$$

$$\sqrt{2\chi^2} - \sqrt{2n-1} = -2 \cdot 01.$$ The fit is good.

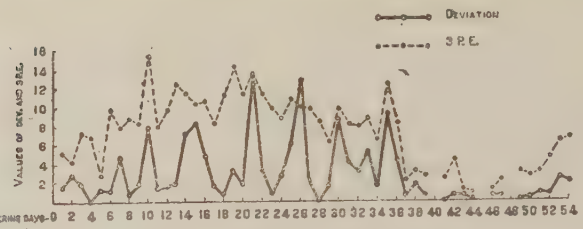


Fig. 2. Stem-colour (*New Hibiscus*×*Albus*).

As before, it could be safely concluded that neither the age of the F_1 plant nor the season has any influence on the F_2 segregation.

The frequencies of the two phenotypes for the entire flowering period are as follows :—

——	Red stem (various grades)	Green stem	Total
Total observed	3357	1117	4,474
Total expected on 3 : 1 basis	3355·5	1118·5	4,474
Deviation	1·5	1·5	

$$\frac{\text{Dev,}}{\text{P. E.}} = \frac{1{\cdot}50}{1953} = 0{\cdot}08$$

The fit is, therefore, excellent.

The ' fit ' to a 3 : 1 ratio was good for the population of each F_1 plant taken individually.

The " fit " for the frequencies during the whole flowering period was tested and was good.

New Hibiscus × *Ruber*
Leaf-lobe

The *New Hibiscus* has a narrow leaf-lobe and *Ruber*, a broad leaf-lobe. The F_1 had a narrow leaf-lobe and in F_2 a ratio of 3 narrow-lobed plants : 1 broad-lobed plant is expected on theory in the progeny of each successive day. The actual results are shown in the following table :—

TABLE III

Showing the daily frequencies of the two phenotypes, their ratios, total population, deviation between observed and theoretical frequency of the recessive, and 3 P. E.

New Hibiscus × *Ruber*—F_2
Leaf-lobe

Flowering day	Narrow lobe	Broad lobe	Total	Ratio	Deviation	3 P. E.
1	19	11	30	1·73	+3·50	4·80
2	27	4	31	6·75	—3·75	4·88
3	52	20	72	2·60	+2·00	7·44
4	36	15	51	2·40	+2·25	6·25
5	75	24	99	3·12	—0·75	8·72
6	125	46	171	2·72	+3·25	11·47

TABLE III—*contd.*

Flowering day	Narrow lobe	Broad lobe	Total	Ratio	Deviation	3 P. E.
7	110	43	153	2·56	+4·75	10·84
8	94	33	127	2·85	+1·25	9·9
9	38	16	54	2·37	+2·50	6·43
10	144	38	182	3·79	—7·50	11·82
11	43	21	64	2·05	+5·00	7·01
12	43	18	61	2·39	+2·75	6·84
13	43	13	56	3·31	—1·00	6·55
14	105	38	143	2·76	+2·25	10·48
15	57	18	75	3·17	—0·75	7·58
16	50	17	67	2·94	0·25	7.17
17	108	28	136	3·86	—6·00	10·24
18	64	23	87	2·78	+1·25	8.17
19	202	68	270	2·97	+0·50	14·36
20	150	59	209	2·54	+6·75	12·70
21	101	28	129	3·61	—4·25	9·95
22	81	38	119	2·13	+8·25	9·63
23	58	19	77	3·05	—0·25	7·68
24	89	32	121	2·78	+1·75	9·63
25	88	27	115	3·26	—1·75	9·37
26	126	38	164	3·32	—3·00	11·21
*27	119	56	175	2·13	+12·25	11·56
28	57	20	77	2·85	+0·75	7·68
29	51	20	71	2·55	+2·25	7·38
30	56	16	72	3·50	—2·00	7·44
31	36	16	52	2·25	+3·00	6·31
32	42	13	55	3·23	—0·75	6·50
33	53	14	67	3·79	—2·75	7·17
34	31	9	40	3·44	—1·00	5·53
35	49	9	58	5·42	—5·50	6·67
36	30	17	47	1·76	+5·25	6·01
37	13	4	17	3·25	—0·25	3·61
38	5	2	7	2·50	+0·25	2·32
39	1	2	3	0·50	—1·25	1·52
40	6	2	8	3·00	0·00	2·88
41	2	1	3	2·00	+0·25	1·52
42	6	2	8	3·00	0·00	2·48
43	5	1	6	5·00	—0·50	2·15
44	1	0	1	0·00	—0·25	0·88
45	1	1	2	1·00	+0·50	1·24
46			No setting			
47			,, ,,			
48			,, ,,			
49			,, ,,			
50	0	1	1	0·00	+0·75	0·88
51			No setting			

*Here the deviation, being greater than 3 P. E., is significant,

TABLE III—*concld.*

Flowering day	Narrow lobe	Broad lobe	Total	Ratio	Deviation	3 P. E.
52	21	7	28	3·00	0·00	4·63
53	42	15	57	2·80	+0·75	6·61
54	15	4	19	3·75	—0·75	3·82

$\chi^2 = 39{\cdot}08$

$\sqrt{2\chi^2} - \sqrt{2n-1} = -1{\cdot}01$. The fit is good.

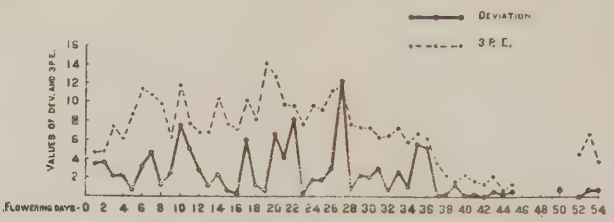


FIG. 3. Leaf-lobe (*New Hibiscus* × *Ruber*).

The table and Fig. 3 do not show seasonal or age (of F_1) effect on the segregations, the deviation between the observed and theoretical frequencies being significant only on the 27th day. Thus the conclusion as in the previous cases is that the F_2 ratios are not affected by the time of selfing of the F_1 plants, nor by any other factor so far as this character, *viz.*, leaf-lobe, in *Hibiscus* is concerned.

The F_2 phenotypic frequencies for the entire flowering period are as follows :—

	Narrow-lobed plants	Broad-lobed plants	Total
Total observed	2770·00	967·00	3,737
Total expected on 3 : 1 basis	2802·75	934·25	3,737
Deviation	32·75	32·75	

$$\frac{\text{Dev.}}{\text{P. E.}} = \frac{32{\cdot}75}{17{\cdot}73} = 1{\cdot}85$$

The fit, therefore, is good.

Out of the five F_2 populations from the five F_1 plants " fits " to a 3 : 1 ratio were good in four cases and bad in one.

The " fit " for the frequencies during the whole flowering period was tested and was good.

Stem-colour.—New Hibiscus has a green stem with red patches in the leaf-axil and below it. *Ruber* has a red stem. In F_1, the stem was red. In F_2, a ratio of 3 red-stemmed plants (like *Ruber* and F_1) : 1 green-stemmed with patches is

theoretically expected. The actual observed results for each flowering day are given in the following table :—

TABLE IV

Showing the daily frequencies of the two phenotypes, their ratios, total population, deviation between observed and theoretical frequency of the recessive and 3 P. E.

New Hibiscus × *Ruber* F_2

Stem-colour

Flowering day	Red stem	Green stem	Total	Ratio	Deviation	3 P. E.
1	22	7	29	3·14	—0·25	4·72
2	25	6	31	4·17	—1·75	4·88
3	55	15	70	3·33	—2·50	7·33
*4	30	21	51	1·43	+8·25	6·25
5	81	18	99	4·50	—6·75	8·72
6	122	50	172	2·44	+7·00	11·49
7	119	36	153	3·31	—2·25	10·84
8	94	33	127	2·85	+1·25	9·90
9	35	19	54	1·84	+5·50	6·43
10	141	47	188	3·20	0·00	12·00
11	50	14	64	3·57	—2·00	7·01
12	41	20	61	2·05	+4·75	6·84
13	35	15	50	2·33	+2·50	6·19
14	112	32	144	3·75	—4·00	10·51
15	58	19	77	3·05	—0·25	7·68
16	57	12	69	4·75	—5·25	7·28
17	105	32	137	3·28	—2·25	10·25
18	62	23	85	2·70	+1·75	8·08
19	189	82	271	2·31	+14·25	14·45
20	156	53	209	2·95	+0·75	12·70
*21	75	39	114	1·92	+10·50	9·37
22	95	35	130	2·71	+2·50	9·98
23	61	16	77	3·81	—3·25	7·68
24	83	38	121	2·18	+7·75	9·63
25	82	33	115	2·58	+4·25	9·37
26	115	49	164	2·35	+8·00	11·21
*27	115	64	179	1·79	+19·25	11·74
28	52	25	77	2·08	+5·75	7·68
29	53	19	72	2·79	+1·00	7·44
30	57	15	72	3·80	—3·00	7·44
31	40	12	52	3·33	—1·00	6·31
32	40	15	55	2·67	+1·25	6·50
33	52	16	68	3·25	—1·00	7·23
34	28	13	41	2·15	+2·75	5·61
35	47	12	59	3·92	—2·75	6·73
36	30	15	45	2·00	+3·75	5·88
37	17	5	22	3·40	—0·50	4·11
38	4	3	7	1·33	+1·25	2 32
39	1	2	3	0·50	+1·25	1·52

TABLE IV—*contd.*

Flowering day	Red stem	Green stem	Total	Ratio	Deviation	3 P. E.
40	6	2	8	3·00	0·00	2·48
41	2	1	3	2·00	+0·25	1·52
42	5	3	8	1·67	+1·00	2·48
43	5	1	6	5·00	—0·50	2·15
44	1	0	1	0·00	—0·25	0·88
45	2	0	2	0·00	—0·50	1·24
46			No setting			
47			,, ,,			
48			,, ,,			
49			,, ,,			
50	1	0	1	0·00	—0·25	0·88
51			No setting			
*52	15	13	28	1·15	+6·00	4·63
53	39	20	59	1·95	+5·25	6·73
54	15	4	19	3.75	—0·75	3·82

*Here the deviations, being greater than 3 P. E., are significant.

$\chi^2 = 70 \cdot 594$.

$\sqrt{2\chi^2} - \sqrt{2n-1} = 1 \cdot 95$. The fit is good.

Table IV shows the following facts :—

(1) There seems to be a tendency for the dominants to occur in excess during the first seventeen days with, however, six exceptions. During the next twelve days, on the other hand, there is a tendency for the recessives to be in excess excepting on one day (23rd), and two of the deviations are significant. The later deviations, positive and negative, are fairly random.

(2) During the whole flowering period only four deviations, those on the 4th, 21st, 27th, and 52nd days are significant. In a large majority of cases, *i.e.*, 92 per cent, however, the deviations are due to chance.

Figure 4 shows some of the above points very clearly. Though there is a slight tendency towards a periodic fall and rise in the number of the recessives, yet most of the deviations not being statistically significant, the periodicity may be due to chance, and it cannot be safely concluded that either the age of the F_1 plant, or any other factor has any influence on the F_2 segregation.

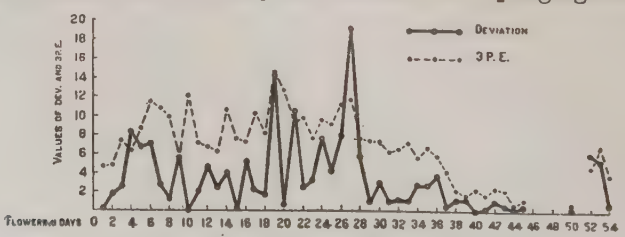


Fig. 4. Stem-colour (*New Hibiscus* × *Ruber*).

The total population for the full flowering period shows the following phenotypic frequencies :—

——	Stem red	Stem green with red patches	Total
Total observed	2,727·00	1,024·00	3,751
Total expected on 3 : 1 basis . .	2,813·25	937·75	3,751
Deviation	86·25	86·25	

$$\frac{\text{Dev.}}{\text{P. E.}} = \frac{86 \cdot 25}{17 \cdot 76} = 4 \cdot 86.$$ The fit is bad.

The excess in the recessives is responsible for a bad fit, but it cannot be accounted for. In one, out of the five different F_2 populations, the " fit " to a 3 : 1 ratio was bad.

The " fit " for the frequencies during the whole flowering period was tested and was good.

IV. Second series of experiments

Two crosses were studied when the experiment was repeated in the year 1934-35. One was *Albus* × *Ruber* with a F_2 population of about 12,600 and the other *Ruber* × *New Hibiscus* with a F_2 population of about 22,000. The latter was a repetition of the previous year's work, the former a new cross, in which both parents possessed a broad leaf-lobe, and stem-colour was the only factor considered. The crosses were made in the year 1932-33.

The hybrid seeds were sown in June, 1933. The germination was uniform in all the F_1 seed. There were six F_1 plants of the former cross and seven of the latter. All the plants began to flower practically at the same time. In the cross, *Albus* × *Ruber*, flowering commenced in one plant on November 2, 1933, and by November 6, 1933, all were in flower. In the other cross, *Ruber* × *New Hibiscus*, flowering commenced on November 3rd, 1933, in one plant, and by November 5th, 1935, all of them were in flower. Selfing was begun from the very commencement of flowering until practically the end of the flowering period in each cross. In the former cross, plants were selfed for about thirty successive days, and in the latter for about sixty succesive days. The flowers towards the end of the season, however, either did not set or only produced very few seeds, and on this account seeds of the first twenty-five days in the former cross and of forty-three days in the latter were sown to grow the F_2 populations.

The methods of sowing, cultivation, selfing, etc., were the same as in the previous year with the difference that nearly all the flowers on each F_1 plant were selfed to ensure large F_2 populations.

The selfed seeds of the F_1 plants were sown on June 20th, 1934. The germination was quite satisfactory unlike that in the previous year, making available for study a population of about 12,600 in the cross *Albus* × *Ruber* and about 22,000 in the cross, *New Hibiscus* × *Ruber*.

The observations were commenced when the plants were about four weeks old. The differences between the different phenotypes were quite clear-cut, and hence there was no possibility of mistaking one phenotype for the other.

The statements of daily segregations, etc., have not been presented in this series of experiments. The results will, however, be clear from the illustrations.

Experimental results

Albus × *Ruber*

Stem-colour.—Albus has a green stem and *Ruber* has red. The F_1 had red stem and in F_2, a ratio of 3 red stems : 1 green stem is theoretically expected [Howard and Howard, 1924] in each day's population. The expectation is realized as will be evident from the results illustrated in Fig. 5.

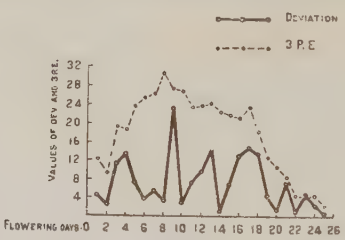


Fig. 5. Stem-colour (*Albus* × *Ruber*).

The figure shows that the ratio of dominants to recessives varies from day to day without any periodicity. It also shows that only one deviation, that on the 23rd, is significant and that in ninety-six per cent cases, the deviations are not significant, being less than 3 P. E.

The following results are obtained when the frequencies for all the flowering days are added up :—

——	Red stem	Green stem	Total
Total observed	9,390·00	3,251·00	12,641
Total expected on 3 : 1 basis . . .	9,480·75	3,160·25	12,641
Deviation	90·75	90·75	

$$\frac{\text{Dev.}}{\text{P. E.}} = \frac{90 \cdot 75}{32 \cdot 83} = 2 \cdot 7.$$ The fit is fairly good.

One F_2 population out of the five has given a bad " fit " to a 3 : 1 ratio.

From the above results it may be concluded that the F_2 results are not influenced by age of the plant or environmental factors.

New Hibiscus × *Ruber*

Leaf-lobe.—The results of the daily segregations of the two phenotypes, narrow or broad leaf-lobe, are shown in Fig. 6. The figure shows that during the first five days the dominants are in excess, while during the next seven days the increase or decrease in them is fairly random. The next twenty days, except one, show an excess of dominants. Then there is again a random occurrence of excess and deficiency in them during the last six days. As will be evident from the figure the deviations are, however, not significant, except on three days, *viz.*, 10th, 12th, and 16th, *i.e.*, in about ninety-three per cent cases.

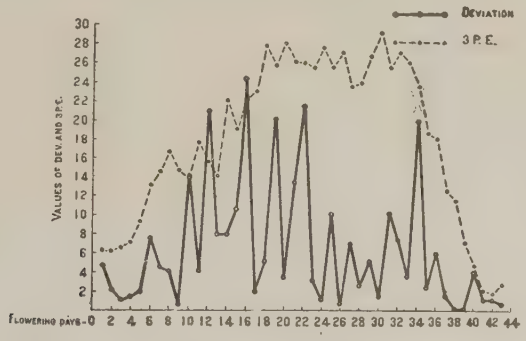


Fig. 6. Leaf-lobe (*New Hibiscus*×*Ruber*).

As before, it may again be concluded that the F_2 ratios are not affected by the age of the F_1 plant or by any other factor.

The combined frequencies for the whole flowering period, which give a good "fit" to a 3 : 1 ratio, are as follows :—

	Narrow leaf-lobed plants	Broad leaf-lobed plants	Total
Total observed	16,686	5,398	22,084
Total expected on 3 : 1 basis . .	16,563	5,521	22,084
Deviation	123	123	

$$\frac{\text{Dev.}}{\text{P. E.}} = \frac{123}{43 \cdot 39} = 2 \cdot 83.$$ The fit is fairly good.

All the five F_2 populations have each given a good "fit" to a 3 : 1 ratio individually.

The "fit" for the frequencies during the whole flowering period was tested and was good.

Stem-colour.—The day-to-day results of the segregations of the two phenotypes, red and green, are illustrated in Fig. 7, from which it will be evident that the daily deviations, positive and negative, from the expected results, occur fairly at random and that except on five days, *viz.*, 10th, 15th, 19th, 30th and 38th they are not significant, being less than three times the Probable Error. That is in only twelve per cent cases the deviations are significant and in eighty-eight per cent cases they are due to chance alone. So, as before, it could be concluded that the age of the F_1 plant, or any other factor does not interfere with the F_2 ratio.

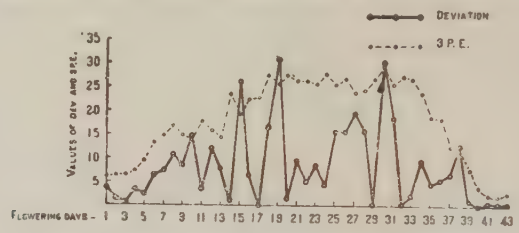


Fig. 7. Stem-colour (*New Hibiscus*×*Ruber*).

The combined frequencies of the two phenotypes for all the flowering days are as follows :—

——	Red stem	Green stem	Total
Total observed	16,396	5,628	22,024
Total expected on 3 : 1 basis . .	16,518	5,506	22,024
Deviation	122	122	

$\frac{\text{Dev.}}{\text{P. E.}} = \frac{122}{43 \cdot 33} = 2 \cdot 82$. The fit, therefore, is fairly good.

All the five F_2 populations have given good " fits " to a 3 : 1 ratio individually. The " fit " for the frequencies during the whole flowering period was tested and was good.

V. Discussion

The present investigation deals with two different, distinct characters, one, *viz.*, stem-colour in three different crosses and the other, *viz.*, leaf-lobe in two different crosses, the investigations for one cross having been repeated with a very large population. The results of any of the crosses in either year do not show any significant deviation, periodic or otherwise, in the F_2 ratios.

Considering the first year's results of our investigation, we find that in the cross, *New Hibiscus* × *Albus*, the observed results in the case of the character leaf-lobe significantly deviate only on one day and that all other deviations are not statistically significant. There is no indication of the deviations having a periodic trend. In the stem colour character also the observed results significantly deviate from theoretical ones only on one day during the whole reproductive period of the

plant. Moreover, in the rest of the deviations, which are not significant, there is not the slightest indication of periodicity.

With respect to the other cross, *New Hibiscus* × *Ruber*, the observed results for the leaf-lobe character significantly deviate only once during the entire reproductive period of the mother plant. There is absolutely no indication of any of the deviations being periodic. The results for the other character, *viz.*, stem-colour, show that all the deviations from the expected results, except four, are within the limits of chance errors. There is, however, a slight tendency for the dominants to be in slight excess in the beginning and to be slightly deficient thereafter for a few days. But as judged by the criterion, *viz.*, " goodness of fit ", most of the deviations are not statistically significant, and the slight periodicity, if it be so called, may be taken as due to chance. If one suspects periodic rise or fall in the number of the dominants or recessives in this cross and for the character, leaf-lobe, then it may be questioned as to why this phenomenon did not manifest itself in the second series of experiments when this cross was duplicated with a larger population. The failure of the periodicity to make its appearance in the cross when repeated supports the conclusion that the above periodicity is due to chance.

Considering now the results of the second series of experiments, and taking first the cross *Albus* × *Ruber*, it is seen that only on one day do the observed results deviate statistically from the theoretical. Also there is no indication of the deviations being periodic.

In the other cross, *New Hibiscus* × *Ruber*, the results for the leaf-lobe character show that only on three days out of forty-three do the observed results significantly deviate from the expected ones. No tendency for a periodic rise or fall in the number of either of the phenotypes is indicated. For the stem-colour character, the deviations between the observed and expected results are significant only in four cases, and indication of any periodicity in the results is absent.

VI. Summary and conclusion

The mass of evidence set out in the foregoing paper shows clearly that in the case of *Hibiscus sabdariffa* L., the segregation in the F_2 generation of the characters, leaf-lobe and stem-colour, are not influenced by the time at which fertilisation occurs in the heterozygous parent plants.

Selfing of the F_1 generation may, therefore, be carried out at any stage during the flowering period without danger of disturbing the normal Mendelian ratios.

VII. REFERENCES

Christie, W. and Wriedt, C. (1930). *Hereditas* **14**, 173-196.

Fisher, R. A. (1932). ' Statistical Methods for Research Workers ', 104-105.

Haigh, J. C. and Lochrie, J. V. (1929). *Annals of Botany* **43**, No. 172, 783-803.

Howard, A. and Howard, G. L. C. (1924). *Mem. Dept. Agri. Ind. Bot. Ser.* **13**, No. 3, 47-85.

AN ILLUSTRATION OF THE USE OF THE χ^2 -TECHNIQUE ANALYSIS ON METEOROLOGICAL DATA

BY

P. V. SUKHATME, B.Sc., PH.D. (LONDON),

Statistician, Imperial Institute of Sugar Technology, Cawnpore

(Received for publication on 21st July 1936)

The χ^2-technique of analysis is frequently employed in statistical investigations on biological data. The technique was first given by R. A. Fisher in connection with the problem of estimating the density of bacterial populations in sugar refinery products. It has since been applied in some form or other to numerous other problems of practical value. It is intended here to exhibit its application to yet another problem arising in Agricultural Meteorology and to put it in a suitable form so as to be immediately available for application in practice.

The data* which form the subject of study in this paper relate to the numbers of counts of nuclei made with the Aitken portable counter in the open air at Kew Observatory. In Table I are given the results of 240 such counts, which were completed in about an hour, a short pause being made at every five minutes in order to write down the figures.

A column contains the results of twenty consecutive counts which occupied about five minutes. The object is to ascertain whether a genuine change was brought about in the nucleus-content of the air during the hour of observation or else the fluctuations in counts were simply due to errors of random sampling.

Now it has been shown by F. J. Scrase that if the nuclei in air are distributed at random, then the probability of occurrence of a count of a given value is given by the term of the Poisson Series. Consequently regarding the data in Table I as having been drawn in random sampling from one or more Poisson distributions, the enquiry reduces to direct application of χ^2-tests to these data as described by Fisher.

* These data have been discussed by F. J. Scrase in his paper ' On the Sampling Errors of the Aitken Nucleus Counter, ' *Jour. Roy. Met. Society*, London. Vol. LXI, 1935. These were kindly sent to me, at my request, for further analysis.

TABLE I

Kew Observatory : Nucleus counts made on December 29th, 1933

	1	2	3	4	5	6	7	8	9	10	11	12	
G. M. T.	11.47½	11.52½	11.57½	12.02½	12.07½	12.12½	12.17½	12.22½	12.27½	12.32½	12.37½	12.42½	
1	6	8	4	4	3	8	5	8	7	4	8	6	
2	3	11	8	5	2	8	10	6	4	11	1	10	
3	4	6	6	7	3	4	6	4	4	8	4	11	
4	6	6	9	8	6	9	6	5	8	6	1	3	
5	7	11	7	3	4	15	5	7	2	6	5	3	
6	4	7	9	10	8	16	7	7	5	4	6	2	
7	3	8	3	13	9	8	3	7	3	7	6	1	
8	10	6	3	12	7	11	6	5	2	8	0	1	
9	4	3	9	11	12	7	4	8	5	6	7	2	
10	6	6	8	5	4	14	6	3	4	6	4	3	
11	5	9	6	8	7	17	7	11	8	7	5	6	
12	7	8	8	7	2	7	4	5	6	7	5	1	
13	4	6	11	7	3	5	2	5	3	6	7	6	
14	5	5	15	3	1	6	2	6	4	6	6	4	
15	10	10	8	5	5	6	4	5	5	7	8	3	
16	8	11	6	11	6	10	7	4	6	9	14	4	
17	6	4	5	8	4	5	4	5	6	1	4	4	
18	10	7	7	7	6	4	4	4	5	11	6	5	
19	6	8	6	4	2	4	4	5	4	5	2	5	
20	8	11	2	6	2	12	4	5	7	2	8	3	
Totals C_i	122	151	140	144	98	176	100	115	98	127	107	83	
χ^2	15.4	14.4	24.3	23.2	26.9	36.0	14.0	11.1	12.2	18.7	34.9	33.4	($\chi^2_{5\%} = 30.1$).

Unlike the 'Analysis of Variance' Technique for Normal Variation, the χ^2-technique does not appear to have been put in a tabular form. In view of its frequent application to biological data, it will be well worth the while to give in a tabular form the χ^2-tests, which are appropriate for the analysis of data coming from the Poisson and binomial populations and then to discuss the data in Table I in the light of these tests.

Suppose we have a type of data arranged as follows in a double classification.

$$\begin{array}{cccc} x_{11} & x_{21} & x_{t1} & x_{k1} \\ x_{12} & x_{22} & x_{t2} & x_{k2} \\ \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot \\ \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot \\ x_{1i} & x_{2i} & x_{ti} & x_{ki} \\ \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot \\ x_{1n} & x_{2n} & x_{tn} & x_{kn} \end{array} \qquad (1)$$

where x_{ti} represents the number of occurrences counted in a fixed time or space interval and the chance that the variable in the t^{th} column and the i_{th} row takes the value x_{ti} is given by

$$\varepsilon^{-m_{ti}} \frac{(m_{ti})^{x_{ti}}}{x_{ti}!} \qquad (2)$$

The problems for consideration before us are whether

(*a*) the variation within columns is no more than might be expected through chance causes

(*b*) the variation between columns is within the limits of errors of random sampling, assuming that the variation within columns is ascribable to pure chance causes

(*c*) the whole set of records could be combined together without loss of homogeneity.

Analogous problems arise in the case of binomial population. The data such as these in Table I may now arise in a variety of ways. Thus, for example,

the n values of x in the t^{th} column may represent the number of infested barley ears in n samples of, say, 100, drawn from the t^{th} plot and k will represent the number of plots ; and the problems for consideration would then be whether the material is homogeneous within a plot, whether the proportion of infestation varies considerably from plot to plot and so on.

The form of χ^2-technique is given in Table II, where in the case of the Poisson Series

$\bar{x}_{t.}$ represents the mean of the t^{th} column

$\bar{x}_{..}$ represents the mean of the total set of observations

and in the case of the Binomial series—

$p_{t.}$ represents the proportion of infested ears on the t^{th} plot

$p_{..}$ is the proportion of infested ears on all the plots

$q_{t.} = 1 - p_{t.}$ and $q_{..} = 1 - p_{..}$

TABLE II

Variation	Sums of squares	χ^2 for Poisson	χ^2 for binomial	f= degrees of freedom
Within classes	$\sum_{t=1}^{k}\sum_{i=1}^{n}(x_{ti}-\bar{x}_{t.})^2$	$\sum_{t=1}^{k}\left\{\frac{\sum_{i=1}^{n}(x_{ti}-\bar{x}_{t.})^2}{\bar{x}_{t.}}\right\}$	$\sum_{t=1}^{k}\left\{\frac{\sum_{i=1}^{n}(x_{ti}-\bar{x}_{t.})^2}{\bar{x}_{t.}q_{t.}}\right\}$	$k(n-1)$
Between classes	$n\sum_{t=1}^{k}(\bar{x}_{t.}-\bar{x}_{..})^2$	$\frac{n\sum_{t=1}^{k}(x_{t.}-x_{..})^2}{\bar{x}_{..}}$	$\frac{n\sum_{t=1}^{k}(\bar{x}_{t.}-\bar{x}_{..})^2}{\bar{x}_{..}q_{..}}$	$k-1$
Total	$\sum_{t=1}^{k}\sum_{i=1}^{n}(x_{ti}-\bar{x}_{..})^2$	$\frac{\sum_{t=1}^{k}\sum_{i=1}^{n}(x_{ti}-\bar{x}_{..})^2}{\bar{x}_{..}}$	$\frac{\sum_{t=1}^{k}\sum_{i=1}^{n}(x_{ti}-\bar{x}_{..})^2}{\bar{x}_{..}q_{..}}$	$kn-1$

The table is similar to that used in the process of the Analysis of Variance for Normal Variation, except for column (3) where the mean square in the Analysis of Variance is now replaced by $\varkappa^2$. The mean square is obtained by dividing the sum of squares of deviations by the corresponding degrees of freedom entered in column (5); the $\varkappa^2$ is obtained by dividing the sum of squares of deviations in a class by the variance of the variate in the class. The computation involved in obtaining a $\varkappa^2$ is extremely simple. If $x_1 \ldots x_n$ are a sample from a Poisson Series

$$\varkappa^2 = \frac{\sum_{i=1}^{n} (x - \bar{x})^2}{\bar{x}}$$

$$= \frac{n \sum_{i=1}^{n} x_i^2}{T} - T \qquad (3)$$

where

$$T = n\bar{x} = \sum_{i=1}^{n} x_i$$

a form which is extremely convenient for computation, noting especially that $x_1 \ldots x_n$ are all integers. For the binomial we have similarly

$$\varkappa^2 = \frac{1}{q} \left\{ \frac{n \sum_{i=1}^{n} x_i^2}{T} - T \right\} \qquad (4)$$

The form of analysis given above is of general application and deals simply with variation within and between classes. Sometimes, however, it may be required to subdivide the total contribution to $\varkappa^2$ into its components corresponding to desired groups of (or single) degrees of freedom. The process is of interest from another point of view; namely of locating the main discrepancy in case a significant value of $\varkappa^2$ is obtained, which may in fact be due to some individual degrees of freedom corresponding to real effects which may be of importance to our enquiry.

This process of subdivision of χ^2 into its components is fully developed by Fisher [1934] and no space will, therefore, be devoted here for its discussion. In its simple form it will be employed in the analysis of data in Table I, which is discussed below.

Following the entries in Table II, the values of the observed χ^2 for variation within and between columns are entered in column 2 of Table III. The corresponding five per cent values are given in column (3). It will be noted that the value of χ^2 for variation within columns is the total of twelve values of χ^2, entered at the bottom of each column in Table I.

TABLE III

Variation	d. f.	χ^2	χ^2 5 per cent	
Within columns	228	264·4	263·9	
Between columns	11	65·9	19·7	

Judged by the five per cent level of significance, the values of χ^2 for variation within and between columns are both significant, although the former is barely so. The values of χ^2 for columns 6, 11 and 12 are mainly responsible for the fat total of 264·4, which represents the χ^2 for variation within columns. With their exception, the variation may effectively be regarded as having arisen due to errors of random sampling.

The significance of χ^2 for variation between columns leaves no doubt whatever on the point that a genuine change had in fact been brought about in the nucleus content of the air. It may, however, be asked whether the significance of the χ^2 value might not solely be due to exceptionally high and low totals for columns 6 and 12. Indeed the χ^2's obtained for these columns suggest that a significant variation in the composition of the air was brought about at the time when observations in these columns were being taken. The contribution to χ^2 for variation between columns can thus be divided into two components χ^2_1 and χ^2_2 the first made by all columns except 6th and 12th and consequently based on nine degrees of freedom, while the latter based on the remaining two degrees of freedom which are orthogonal to the first nine.

Denote the totals for columns in Table I by $C_1 \ldots . C_{12}$. On the hypothesis of equal expectation in all the 12 columns, χ^2_1 is obtained by dividing the sum of squares of deviations of $C_1 \ldots \ldots C_5, C_7 \ldots \ldots C_{11}$ by the variance of Ci which is 1461/12 = 121·75; while χ^2_2 is obtained as the sum of χ^2's corresponding to degrees of freedom given by

$$5(C_6 + C_{12}) - (C_1 + \ldots . + C_5 + C_7 + \ldots + C_{11})$$

and $C_6 - C_{12}$ which are 1·2 and 35·5 respectively.

Thus we have

$\chi^2_1 = 29 \cdot 2$ and $\chi^2_2 = 36 \cdot 7$,

their total being 65·9, agreeing with the value of χ^2 for variation between columns as it should.

The five per cent values of χ^2 based on nine and two degrees of freedom respectively are 16·9 and 6·0. Both χ^2_1 and χ^2_2 are thus seen to be far above their five per cent values, suggesting that the change in the content of the air was not entirely due to two sudden disturbances but was probably brought about gradually.

It is remarkable to note that of the contribution to χ^2_2 made by the two degrees of freedom, namely

$$5\,(C_6 + C_{12}) - (C_1 + \ldots + C_5 + C_7 + \ldots + C_{11})$$

and $C_6 - C_{12}$

the contribution made by the first is only 1·2 while that made by the latter is 35·5, showing how more than half the contribution to total χ^2 for variation between columns is accounted for by a single degree of freedom corresponding to difference between the total number of counts observed from $12 \cdot 12\frac{1}{2}$ to $12 \cdot 17\frac{1}{2}$ and $12 \cdot 42\frac{1}{2}$ to $12 \cdot 47\frac{1}{2}$ respectively. That this contribution made by the contrast $C_6 - C_{12}$ is so high as 35·5 should not, however, be a matter for surprise, since the two values chosen are such that they yield the largest apparent difference between any two values of the set. It is clearly possible that the difference between the highest and lowest values in the case of a fairly large sample will appear significant even though the material forming the sample is undifferentiated and homogeneous ; much more so when the material is known to be heterogeneous as it probably is in our example. The natural remedy to judge the true significance of the selected contrast is, therefore, to raise the usual level of significance in the inverse ratio of the total number of ways in which the values appearing in the contrast could equally be chosen from among the whole set. Since 1 in 20 is the level of significance employed in this paper we should expect that the level of significance for the special contrast should be 1/1320. The probability that the value of χ^2 for a single degree of freedom should be as large as 35·5, which is the value of χ^2 for the contrast $C_6 - C_{12}$, is found from the tables to be smaller than 1/1320, so that in spite of selection, the contrast $C_6 - C_{12}$ is statistically significant judged by the new level of significance thus obtained.

REFERENCE

Fisher, R. A. (1934). ' Statistical methods for research workers '. Oliver & Boyd, London.

STUDIES IN SORGHUM—THE GREAT MILLET

III. ANTHER, POLLEN AND STIGMA

BY

G. N. RANGASWAMI AYYANGAR, B.A., I.A.S.,

Millets Specialist, Agricultural Research Institute,

AND

V. PANDURANGA RAO, M.A.,

Assistant, Millets Breeding Station, Coimbatore

(Received for publication on 26th June 1935)

(With Plates LXVII & LXVIII and two text-figures)

Introduction

The anthesis and pollination of sorghum has been described in the first part of these studies [Rangaswami Ayyangar and Panduranga Rao, 1931]. In this part will be presented some studies on the anther, pollen and stigma--studies that have been in progress since 1931.

The anther

Anther-size.--Variation in anther size is a varietal character. Even when devoid of pollen, the anther sacs in this cereal do not collapse. The sacs were measured closely after emergence.

Table I

[*Length and diameter of anthers*

(Average of 100)

Varieties	Length of anthers in mm.	Diameter of anthers in μ
S. roxb. var. *hians*	3·5	1,086
S. durra.	3·25	1,061
S. nervosum	3·0	975
S. margaritiferum	2·75	888
Andropogon sorghum, var. *technicus*	2·75	876

The reduction in the size of the anther from the grain sorghum types to others with a lax panicle is interesting.

The common grain sorghum is *S. durra*. In the ear-heads of this as in other sorghums there are both sessile and pedicelled flowers. The sessile flowers are hermaphrodite. The pedicelled flowers are mostly abortive, but occasionally bear anthers. These two sets of anthers were measured 100 each and gave an average length of 3·25 mm. and an average width of 998 μ in each set, thus showing no differences in size consequent on sexual atrophy.

Grain sorghums are usually single-stalked. Sometimes there are tillers which give ear-heads. These ear-heads lack vigour and are always markedly loose in contrast to the compact ear-head from the main stalk. The length and breadth of anthers produced on the main head were measured and compared with those on the side shoots (100 each) and no difference was noted between them.

Pollen

The pollen grains of sorghum are smooth and spherical and contain a single germ-pore. They vary in size and are roughly parallel to anther size differences.

Variety	Size range
S. roxb. var. *hians*	43 μ-62 μ
S. cernuum, *S. durra*, *A. S.* var. *technicus*	37 μ-56 μ
S. nervosum, *S. margaritiferum*	37 μ-49 μ

For a comparative study the pollen grains of the wild grass *Andropogon annulatus* L. were measured and gave a range of 25 μ - 37 μ. The lessening of the pollen size in the wild *Andropogon* and in the lax-headed sorghums is very interesting.

Dummy pollen

In the course of examination of innumerable pollen grains in many varieties of sorghum a peculiar kind of pollen is met with. An examination of pollen under the microscope shows constantly a few grains devoid of solid contents (Plate LXVII). In size they are comparatively small and measure 31 μ- 34 μ. They are not shrivelled but retain normal shape owing to the pressure of the sap inside. They usually plasmolyse in the culture medium and do not germinate. These peculiar pollen grains have been provisionally named " dummy pollen ". [Rangaswami Ayyangar and Panduranga Rao, 1935]. Pollen studies have not, so far as we are aware, recorded non-germinating pollen of this peculiar type. Similar pollen has been met with in the allied wild grasses, *Andropogon annulatus* and *Andropogon pertusus* L.

DUMMY POLLEN

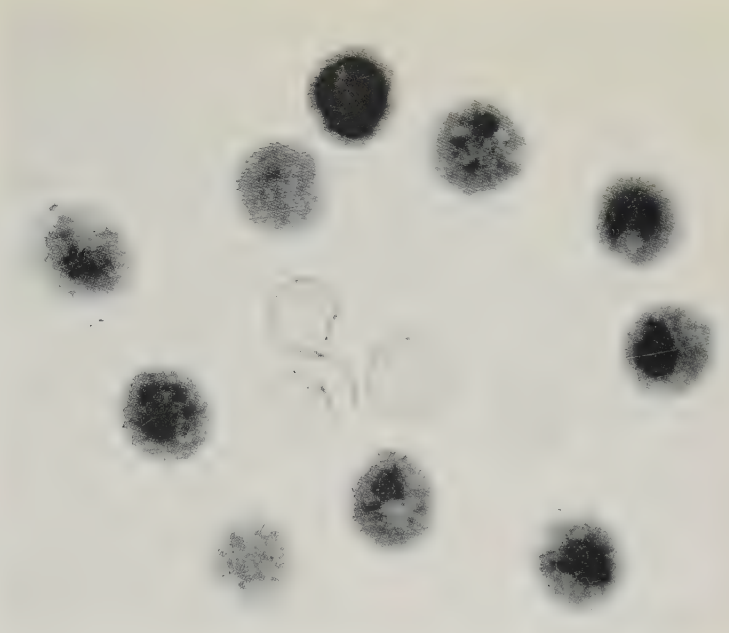


FIG. 1. *Pennisetum typhoides* (×200).

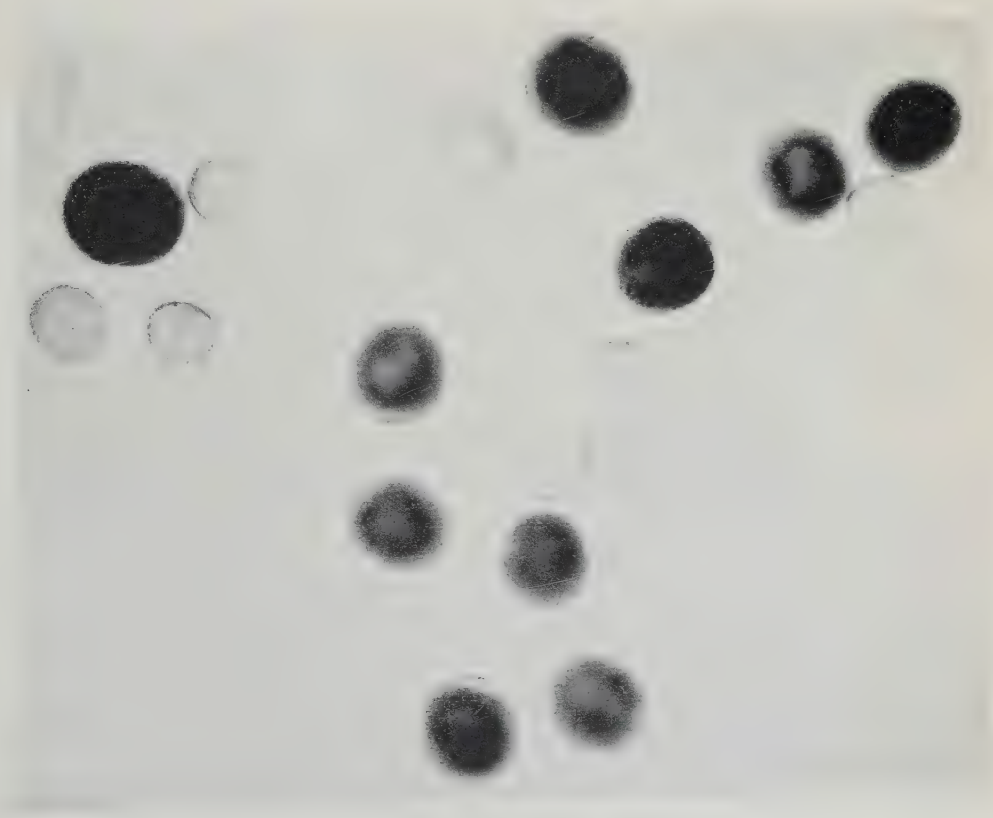


FIG. 2. *Sorghum durra* (×200).

This dummy pollen and the details of its incidence formed the subject of intensive studies. The occurrence of this peculiar pollen varies in the different varieties.

TABLE II

Distribution of dummy pollen in sorghum varieties (from anthers in the middle of the ear-head)

Varieties	Total number of normal grains	Number of dummy pollen grains	Percentage of dummy pollen grains
Rhodesian wild sorghum	4,005	624	13·5
A. S. var. *technicus*	916	113	12·3
S. papyrascens	6,327	615	9·7
S. nervosum	2,115	188	8·8
S. melaleucum	9,757	671	6·9
S. roxb. var. *hians*	1,683	63	3·9
S. durra	2,786	92	3·3
S. cernuum	1,361	32	2·3
S. margaritiferum	1,795	8	0·4
Andropogon annulatus	2,091	111	5·3

It will be seen that the higher types of cultivated varieties have a considerably lower percentage of these dummy grains.

The incidence of 'dummy pollen' shows variations within the ear-head. Several anthers were taken at random from the top, middle and bottom regions of the panicle. Their examination shows that 'dummy pollen' is slightly less in incidence in flowers at the base of the ear-head.

The incidence of the 'dummy pollen' in the unisexual flowers showed no appreciable difference in this respect. It is remarkable that this unisexual condition has not affected either the size or the nature of the pollen population in these anthers.

The occurrence of this kind of ' dummy pollen ' suggested an examination of pollen grains in other millets and it was noticed that no such ' dummy pollen ' could be seen in *Setaria italica, Eleusine coracana* and the *Panicum* millets. It was met with only in *Pennisetum typhoideum* Rich. (a millet of African origin) which, like sorghum, has both hermaphrodite and antheriferous flowers. In this millet this occurrence was noticed in a family in which there was considerable non-dehiscence of anthers. An examination of nearly 5,000 pollen grains in each of the dehisced and undehisced anthers showed the presence of about nine per cent of ' dummy pollen ' in the former and less than one per cent in the latter. This led to a search for similar non-dehiscence in sorghum and in one instance this was met with. In this case, over 10,000 pollen grains in each of the dehisced and undehisced anthers gave about seven per cent of ' dummy pollen ' in the former and only 0·6 per cent in the latter. No defects in the anther sacs were traceable. In these two millets the bulk of the flowers open during the cool hours of the night. In both of them there is a differentiation of flowers into hermaphrodite and antheriferous. The anthers of the antheriferous flowers are in the nature of a reserve to ensure pollination. A similar differentiation of functions in the pollen is, therefore, indicated with a view to ensuring the dehiscence of the anthers.

In this connection it is interesting to record the behaviour of a cross between *S. durra*, the normal grain sorghum and *S. papyrascens*, a papery-glumed sorghum in which there is erratic anthesis. In the second generation of this cross a number of plants with non-dehiscent anthers were met with. This character behaved as a simple recessive to the normal condition. An examination of the pollen grains showed that the non-dehiscence was due to the extreme paucity of ' dummy pollen ' in the anthers. The above segregation is, therefore, virtually a segregation for the requisite proportion of ' dummy pollen ' and the absence of the same leading to non-dehiscence and the attendant sterility (Table III.)

TABLE III

Cross Number	Character of F_1	F_2 Anthers	
		Dehisced with about 7 per cent dummy pollen	Non-dehisced with about 0·1 per cent dummy pollen
A. S. 5. CLII and CLVII.	Dehisced anthers and about 7 per cent dummy pollen . .	106	28
	Expected on 3 : 1 ratio . .	100·5	33·5
	$\chi^2 = 1·2$	P = between 0·2 and 0·3	

Pollen germination

Beyond the experiences of Patel and Patel [1929] and Stephens and Quinby [1934] there is no literature concerning experiences in the germination of pollen grains in sorghum. Patel and Patel found : " With fresh pollen from complete flowers, germination in distilled water took place after 40 minutes ; in 5 per cent glucose solution after 30 minutes ; in 10 per cent glucose solution after 25 minutes and in 15 per cent glucose solution in the few cases where germination took place at all, in about 15 minutes. In this last case, however, the pollen burst after a few minutes. In any case, the germ tube is completely extruded after 5 to 10 minutes." According to Stephens and Quinby : " Some fresh pollen germinated on a glass slide in about 20 minutes after dehiscence of the anthers. The time elapsing before the germination of other pollen grains ranged up to one hour after collection. By that time practically all the pollen had collapsed ".

A number of attempts were made to germinate pollen grains of sorghum at the Millets Breeding Station, Coimbatore. Suffice it to record that the optimum concentration was found to be 41 per cent of sucrose with shred agar from 0·75 to 1·5 per cent. Experiments showed that the pollen germination was sensitive to the seasonal variation. In summer (May-June) 0·75 per cent of shred agar with 41 per cent of sucrose gave the best results, but in winter (November-December) 1·5 per cent shred agar was necessary. The germination of sorghum pollen is thus seen to be dependent on a delicate adjustment of the medium. It is so subtly sensitive to the environment that slight changes in the concentration of the medium result in an appreciable drop in the germination percentage.

TABLE IV

Optimum medium—Cultures on different days

Material — *S. durra* With 0·75 per cent agar

39 per cent sucrose			40 per cent sucrose			41 per cent sucrose			42 per cent sucrose		
Number of pollen grains on the medium		Percentage of pollen germinated	Number of pollen grains on the medium		Percentage of pollen germinated	Number of pollen grains on the medium		Percentage of pollen germinated	Number of pollen grains on the medium		Percentage of pollen germinated
Sown	Germinated		Sown	Germinated		Sown	Germinated		Sown	Germinated	
626	62	10·0	432	206	47·6	426	170	39·8	503	62	12·3
539	89	16·5	620	190	30·6	558	354	63·4	611	114	18·6
430	90	20·9	366	169	46·1	447	263	58·8	325	96	29·5
...	...	...	175	132	75·0	414	178	43·0	382	107	27·0
...	...	...	349	173	49·5	302	178	59·0	...	...	...
...	...	...	364	104	28·6	335	189	56·4	...	...	...
...	...	...	...	...	...	340	189	55·6	...	...	...
...	...	...	...	...	...	529	377	71·2	...	...	...
Average		15·1			42·2			56·6			20·8

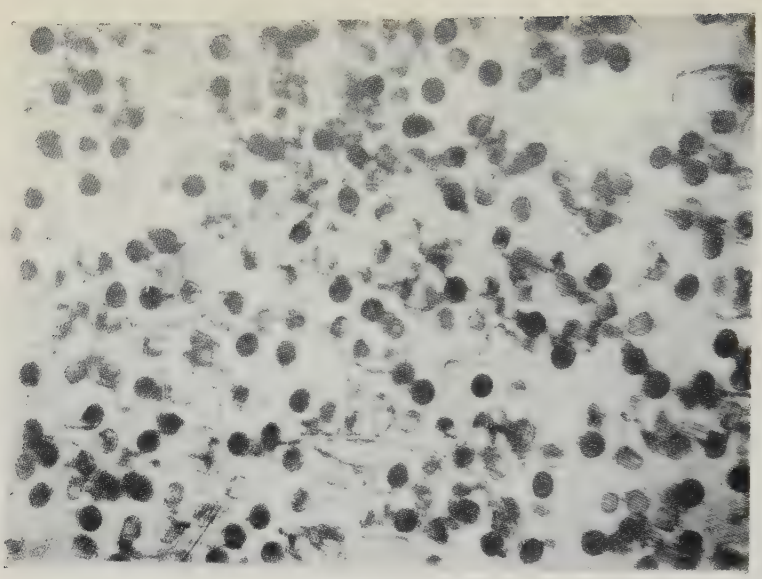


FIG. 1.— Germinating pollen of *S. margaritiferum* (×100)

S. durra. *S. nervosum.*

FIG. 2.—Stigmas (×15).

Portions of stigmas added to the germinating culture medium did not show any preferential germination of pollen near their proximity and the pollen tubes betrayed no tendencies to grow towards them. The germination of pollen usually commences a quarter to half an hour after the pollen has been sown on the medium (Plate LXVIII). It takes three-four hours to complete the growth. A single pollen-tube is the rule. Branched tubes are met with rarely. It is a common occurrence for pollen-tubes to burst at various stages of their growth.

The response of different varieties to artificial germination was tried. The results are recorded in Table V. In this and subsequent tables, unless otherwise mentioned the material used is *S. durra* and the standard culture medium for germination was forty-one per cent sucrose with agar.

TABLE V

Germination of pollen of sorghum varieties in artificial media

Varieties	Number of pollen grains on the medium		Percentage of germination
	Sown	Germinated	
Summer (irrigated)—			
S. durra, var.			
Chinna Manjal	3,050	1,719	56·5
Sen Cholam	1,051	546	51·1
Cold weather—			
Night flowering.			
S. cernuum, var.			
Tella Jonna	8,760	5,580	57·0
S. durra, var.			
Peria Manjal	5,489	2,713	49·4
S. roxb. var. *hians.*			
Talai-virickan	8,840	3,833	43·3
S. nervosum, var.			
Irungu	5,557	1,902	34·2
Andropogon Sorghum, var. *technicus.*			
Broomcorn	2,977	447	15·0
Day flowering.			
S. margaritiferum, var.			
Zomba	10,132	9,040	88·8
Wild allies.			
Andropogon annulatus	6,104	4,074	66·7
Andropogon pertusus	4,410	449	10·2

The different varieties are thus seen to be extremely variable in their response to artificial germination of their pollen grains. The high germinations that were obtained are noteworthy in view of the usual poverty of response common in cereal pollen.

It was next attempted to compare the germination of pollen from bisexual and male flowers. It will be seen from Table VI that in the percentage of germination, the average length of the pollen-tube as well as the maximum length attained by the tubes, the pollen from bisexual spikelets proved to respond better than the pollen from the staminate flowers. Pollen gathered in warm weather showed retarded pollen-tube growth.

TABLE VI

Pollen from bisexual and male flowers

	Number of pollen grains on the medium		Percentage of germination	Average length of pollen-tube	Maximum length of pollen-tube
	Sown	Germinated			
				μ	μ
Pollen from—					
Bisexual flowers.	17,379	10,503	60·4	260	1,296
Male flowers .	17,142	6,464	37·7	92	642

The germination percentage as well as the germination energy of pollen from staminate flowers is seen to be less than that of the hermaphrodite flowers. Seed-setting with these two kinds of pollen was tried on a small scale, with the following results.

TABLE VII

Pollen from bisexual and male flowers—seed-setting

	Number of flowers emasculated and pollinated	Number of seeds set	Percentage of seed-setting
Pollen from bisexual flowers . . .	73	35	48·0
Pollen from male flowers	79	14	17·7

Germinations were tried of pollen from anthers taken from the different parts of the ear-head. Those from the base of the ear-head showed the longest pollen-tube growth.

Pollen being available from 2 A. M., it was next sought to find out the maximum germination energy of pollen grains gathered and set for germination at hourly intervals from 2 A. M. to 10 A. M.

TABLE VIII

Influence of the time of day on pollen germination

Time at which cultures were set up	Number of pollen grains on the medium		Percentage of pollen germinated	Average length of pollen-tube	Maximum length of pollen-tube
	Sown	Germinated			
				μ	μ
2 A. M. . .	1,735	541	31·2	33	74
3 „ . .	2,042	830	40·6	59	197
4 „ . .	1,696	630	37·1	60	383
5 „ . .	2,228	1,060	47·6	79	469
6 „ . .	2,526	1,438	56·9	96	617
7 „ .	1,947	1,012	51·4	165	827
8 „ .	2,135	1,192	55·9	130	1,271
9 „ . .	1,831	614	35·1	123	469
10 „ . .	1,566	333	21·2	123	864

A steady increase is noticed till 8 A. M., when the maximum is reached, after which there is a decline. So also in the rate of growth of the pollen-tube.

Similar germinations were made with pollen from staminate flowers with no appreciable differences except the absence of the drop at 9 A. M. and 10 A. M.

Pollen from mature unopened flowers gave a normal germination response.

Temperature.—To determine the effect of temperature on pollen growth pollen was sown on the culture medium and grown at varying controlled artificial temperatures The germination records were taken after eight hours.

TABLE IX

Effect of temperature on the viability of pollen

(Control—27°C.)

Temperatures	Number of pollen grains on the medium		Percentage of germination
	Sown	Germinated	
10°C.	3,161	2,628	83·1
30°C.	1,680	954	56·6
35°C.	2,522	1,271	50·4
40°C.	2,699	1,285	47·6
50°C.	1,236	163	13·1

Low temperatures have a distinctly beneficial effect on pollen growth. As much as twenty-five per cent over those of the control temperature could be claimed in their favour. This accounts for cold days and the colder hours of the day tending to be more favourable for pollen germination. The figures show that high temperatures up to 35°C. ensure about fifty per cent germination, that at 40°C. this percentage is likely to be kept up and that an increase to 50°C. gives a sudden drop in germination.

Light.—Fresh pollen was carefully folded in two paper packets and kept in a beaker in moist chambers. A black paper wrapped well round one of the moist chambers cut off all light. Samples were sown from the control as well as that in darkness after forty-eight hours.

TABLE X

Effect of light on pollen

	Number of pollen grains on the medium		Percentage of germination
	Sown	Germinated	
Light	1,296	367	28·3
,, (duplicate)	1,492	392	27·4
,, (triplicate)	1,454	395	27·2
Darkness	1,328	44	3·3
,, (duplicate)	1,550	47	3·0
,, (triplicate)	1,242	*Nil*	*Nil*

The inhibiting effects of darkness on pollen germination are patent. The effect of light on pollen growth in artificial media being thus determined, its effect on growth on stigma was next attempted. It was found that flowers pollinated with pollen exposed to light resulted in thirty-six per cent of successful seed-setting while those dusted with pollen from darkness for twenty-four hours resulted in complete sterility. This favourable effect of light on pollen germination has to be remembered in connection with the higher germination percentage of the day flowering *S. margaritiferum*.

Growth of the pollen-tube.—A great difficulty in following up the progress of the growth of the pollen-tube is its tendency to burst. This may happen at any stage of the observation and is not surprising in view of the delicate equipoise that is necessary between the culture medium and the contents of the pollen-tube. A slight disturbance in the balance is enough to arrest growth and the tubes burst. This increases the difficulties of observation and many tubes had to be abandoned on this account.

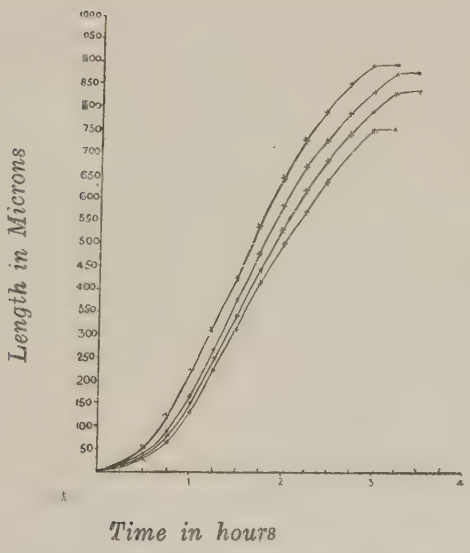


Fig. 1. Growth curves of pollen-tubes from bisexual flowers—A. S. 3065.

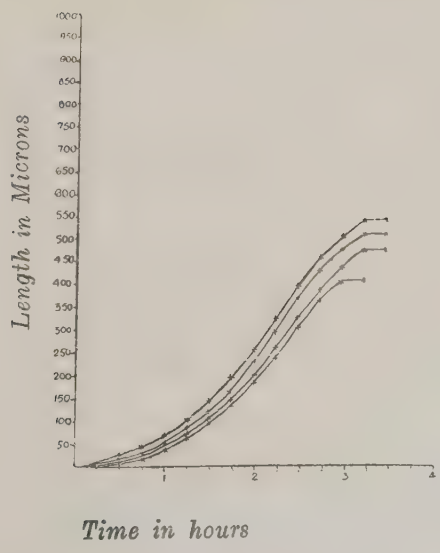


Fig. 2. Growth curves of pollen-tubes from staminate flowers—A. S. 3065.

The growth curve of four pollen-tubes from bisexual flowers have been plotted in the graphs (Figs. 1 and 2). They all show the same general tendency—a preliminary period of growth, a rapid elongation and a gradual decline—giving the curve a somewhat shallow S shape. The first hour of growth is not very rapid but after that it gathers momentum and the greatest elongation is about that time. The decline is more gradual than the earlier acceleration.

The growth curve of the pollen from the staminate flowers has the same general shape and tendency but the rate of growth is different. It is not only slow at first, but continues at a slow pace for a much longer period. After this belated period of initial growth some speed is attained and as in the other cases, is followed by a gradual decline. The tubes are never able to reach the same length as those recorded for the pollen from bisexual flowers.

In nature, therefore, the pollen from staminate flowers is considerably handicapped. It is not numerous, is comparatively poor in germination, and slow and feeble in growth, rarely attains the length of the tubes of the pollen from bisexual flowers, and is consequently not so effective in fertilisation. These handicaps are in tune with the general degeneracy of the pedicelled spikelet.

Nucleus.—In most cases of germinating pollen, the lengths of pollen-tubes obtained in artificial cultures are negligible compared with the distance these tubes have to traverse to reach the ovary. In sorghum also it was not possible to secure the requisite lengths. The maximum length of tube obtained was 1,300 μ as against the 5 mm. necessary to reach the ovary.

Due to the dense contents of the pollen grains of sorghum, in many cases, the nuclei did not take the stain. Belling's Iron-aceto-carmine I was used to stain the nuclei. Prior to the shedding of pollen, there is only one big nucleus in the pollen grain. Shed pollen shows a tube nucleus and two generative nuclei. It is, therefore, probable that this differentiation of nuclei takes place at the time of shedding. The tube nucleus is generally larger than the generative nuclei. Sometimes it does not take the stain and when it does stain, it is usually lighter than the generative nuclei. The tube nucleus is usually at the grain end. In a few cases in *Andropogon annulatus*, the tube nucleus migrates far into the tube. When this occurs all the three nuclei are found together. In *S. margaritiferum* and *Andropogon annulatus* the nuclei are more or less spindle-shaped. In *S. durra*, the nuclei are larger and more elongated. The position of the generative nuclei follows no general rule. They are generally separated but sometimes are found close together. They may be found anywhere along the entire length of the tube. It is not necessary for pollen-tubes to be particularly long for the nuclei to migrate. Even in short tubes they are in evidence. In many cases,

though a considerable length of pollen-tube is attained, the nuclei had not migrated. In ungerminated pollen grains, in artificial cultures, what appear to be normal nuclei for all outward appearances, are found. In the light of these observations it is difficult to assess the influence of the nuclei on pollen-tube growth.

Pollen longevity.—The problem of preserving the pollen for some time without adversely affecting its vitality is a very important one. In practical plant-breeding, it frequently happens that two different strains, which it is desired to cross, do not have a common flowering period. If, therefore, the pollen of one could be kept viable until the required time, a great practical difficulty would be solved. Apart from it, the problem compels interest.

According to Patel and Patel [1929], sorghum pollen is capable of germination for at least thirty hours. The method of storage is not given by them. Stephens and Quinby [1934] find at Chillicothe, United States of America, that after five hours sorghum pollen loses its viability.

The moisture-content of pollen of *S. durra* was estimated to be about fifty per cent by drying the pollen *in vacuo* over sulphuric acid at laboratory temperature and pressure until a constant weight was reached. Sorghum pollen exposed to the atmosphere shrivels in about half an hour. Pollination with shrunken pollen does not set seed. *In vitro* it swells but does not germinate. Desiccating agents like sulphuric acid and calcium chloride quickly kill the pollen. Pollen preserved in an atmosphere of carbon dioxide failed to germinate. Similarly under reduced pressure sorghum pollen failed to germinate though several successes in the case of other kinds of pollen have been reported.

In sorghum, saturated moist conditions were found not to be lethal. The pollen does not shrink. Small packets of pollen were kept in beakers and the whole enclosed in moist chambers. Under these conditions germinations (about 28 per cent) were obtained after forty-eight hours. But after that fungus attack killed the pollen. It is difficult to say whether moist conditions *per se* can preserve the pollen. But, however carefully the experiments were conducted, infection by fungi occurred ; the probabilities are that moisture is not a very efficient preservative agent, for the germination percentage is greatly reduced.

The effect of low temperatures was next tried. Small paper packets of pollen kept in open tubes were preserved in an ice chest at 10°C. This gave the best results and life lingered till even the sixth day. This is the longest period that could be got. All other attempts to further prolong life proved futile.

TABLE XI

Pollen longevity—in vitro

Pollen from bisexual flowers

Age of pollen	Number of pollen grains on the medium		Percentage of germination
	Sown	Germinated	
24 hours old	2,026	521	25·7
48 „ „	2,189	496	22·5
72 „ „	2,241	412	18·4
96 „ „	2,318	309	13·3
120 „ „	2,296	175	8·0
144 „ „	2,176	24	1·1

It was thought that possibly there might be better germination on the stigma, because pollen six days old may not react normally towards the medium prepared with reference to fresh pollen.

TABLE XII

Pollen longevity—on the stigma

Pollen from bisexual flowers

Age of pollen	Number of pollen grains on the medium		Percentage of germination
	Sown	Germinated	
24 hours old	1,114	204	18·3
48 „ „	1,520	180	11·8
72 „ „	1,087	58	5·4
96 „ „	832	9	1·1
120 „ „	830	2	0·2
144 „ „	1,447	2	0·1

For all ordinary purposes the germination capacity may be taken as an index of its general viability. But viability does not necessarily imply ability to fertilise. Further tests were, therefore, made.

TABLE XIII

Pollen longevity—seed-setting

Pollen stored at 10°C. in an ice-chamber

Pollen from bisexual flowers

Age of pollen	Number of flowers emasculated and pollinated	Number of seeds set	Percentage of seed-setting
24 hours old	38	10	26·3
72 „ „	42	13	21·0
96 „ „	46	2	4·3

The pollen is capable of fertilising up to the third day though in a very weak measure. Dead pollen differs little from living pollen in appearance. Germination test is the only sure guide as death does not alter the shape of the grains. Owing to the weak fertilization an abundance of pollen grains seems indicated as a necessity in the case of pollination deferred so long. This experience is in marked contrast to that of Stephens and Quinby [1934].

THE STIGMA

The stigma has not commanded the same attention as the pollen. The literature on it is very scanty. The stigma is a much more difficult material to make observations on and does not lend itself to the same easy handling as the pollen. Most of the work has, therefore, been on the main issue of stigmatic receptivity. Pollen detaches from the flower and is easily handled. The stigma has the disability of being stationary. This difficulty was minimised by cutting off the ear-head and placing the stalk in water. It was noticed that this did not interfere with the opening of the flower and attendant phenomena for a considerable time. By this method, it was possible to easily study the reactions of the stigma under different experimental conditions.

Variations in the style and stigma.—The details of the floral morphology of sorghum have already been given [Rangaswami Ayyangar, and Panduranga Rao, 1931]. The stigma have the shape of a truncated spindle. Two shapes in this spindle can be made out—a brush like type which is the commonest and a bushy one characteristic of *S. roxb.* var. *hians* and *S. nervosum.* The middle branches in a stigma are the longest. The length of branches diminishes gradually towards both ends ; the topmost branch is, however, shorter than the lowest.

TABLE XIV

Length of stigmatic branches

(Average of 100 readings)

Varieties	Length of stigmatic branches at		
	Base	Middle	Top
	μ	μ	μ
S. durra	370	555	222
S. cernuum	344	530	185
S. nervosum	308	456	173
S. roxb. var. *hians*	246	456	197
S. margaritiferum	185	344	98
A. S. var. *technicus*	173	344	123

Variations have been found in the lengths of the style and stigmatic portions and in the combined length of the style and stigma. A typical pure line from each of the following varieties was taken and measurements were recorded (average of 100 readings).

TABLE XV

Variation in the length of style and stigma

Varieties	Length of		Total length of style and stigma mm.	Ratio of style and stigma
	Style mm.	Stigma mm.		
S. cernuum	2·25	2·25	4·50	1 : 1
S. durra	2·00	2·00	4 00	1 : 1
S. margaritiferum	1·75	1·75	3·50	1 : 1
A. S. var. *technicus*	1·50	1·50	3·00	1 : 1
S. roxb. var. *hians.*	2·50	1·25	3·75	2 : 1
S. nervosum	2·50	1·00	3·50	2·5 : 1

It will be seen that the combined lengths of the style and stigma is the greatest in *S. cernuum* and *S. durra* ; most of the cultivated varieties belong to the latter. This length is least in *S. nervosum*, the reed-like fodder variety in which the grains just peep out of the glumes. The other varieties have intermediate lengths. In *S. durra*, *S. cernuum*, *S. margaritiferum*, and *A. S.* var. *technicus*, the style and stigma are equal in length. In *S. roxb.* var. *hians*, and *S. nervosum*, the length

of the stigma is short and is about a third of the combined length of the style and stigma (Plate LXVIII, Fig. 2). An interesting correlation between the length of the subule and column of the awn and of the style and stigmatic zones of the stigma has been recorded. [Rangaswamy Ayyangar and Panduranga Rao, 1935].

Receptivity.—The receptivity of the stigma and the growth of the pollen on and through it was studied. Stigmas were chosen from flowers that open next morning. From the panicle all but twenty or thirty flowers were clipped off. The remaining flowers were emasculated in the evening and pollinated the next morning. After eight hours the germinating pollen was studied after staining. The stain used was 0·08 grm. of cotton blue in 100 c.c. of lactic phenol diluted with an equal quantity of water. The pollen-tubes and grains took the stain in about half an hour. The pollen may germinate on the stigma, but seed-setting need not necessarily follow. In these studies, wherever possible, seed-setting was studied concurrently with pollen germination. So far as stigma receptivity in sorghum is concerned, pollen germination leads to fertilisation.

Temperature.—After emasculation one panicle was kept in the incubator at 10°, 30° and 34°C. Another panicle was kept outside as control. The next morning fresh pollen was dusted on both and eight hours later the stigmas were killed. Counts of pollen germinated and ungerminated on the stigma were made with the aid of an Okular Netz micrometer (Zeiss).

TABLE XVI

Effect of temperature on the receptivity of the stigma

Temperature	No. of pollen grains on the stigma		Percentage of germination
	Sown	Germinated	
10°C.	2,885	2,690	93·2
Control (26·5°C.)	3,177	2,661	83·7
30°C.	1,426	846	59·0
Control (26·5°C.)	2,443	2,109	86·0
34°C.	4,231	1,004	23·7
Control (26·5°C.)	7,857	7,403	94·0

The results show the adverse effect of a temperature of 30°C. and over on the stigma and the favourableness of the lower temperature. Low temperature is thus found to be favourable both for the germination of pollen and the receptivity of the stigma.

Humidity.—Fresh pollen was dusted on the stigmas kept in a moist chamber under saturated moist conditions overnight. Counts show that such humid conditions reduce the receptivity of the stigma.

TABLE XVII

Effect of humidity on the receptivity of stigma

Treatment	Number of pollen grains on the stigma		Percentage of germination
	Sown	Germinated	
Saturated moisture	21,877	4,090	18·7
Control	7,857	7,403	94·0

Desiccation.—For the moist chamber in the above experiment a desiccator with calcium chloride was substituted. This desiccation of the atmosphere for about twenty hours had no effect on its receptivity to fresh pollen applied after such desiccation.

TABLE XVIII

Effect of desiccation on the receptivity of stigma

Treatment	Number of fresh pollen grains on the stigma		Percentage of germination
	Sown	Germinated	
Dry	2,784	2,462	88·4
„ (duplicate)	3,096	2,756	89·0
„ (triplicate)	2,761	2,521	91·0
Control	2,985	2,765	92·6
„ (duplicate)	3,111	2,851	91·6
„ (triplicate)	3,165	2,850	90·0

Light.—To test the effect of light on the stigma on the plant in the field two emasculated sets of flowers on the same panicle were chosen. One of these was wrapped in a fine tissue-paper bag and the other in a fine black paper bag, so as to cut off all light. Fifteen hours later, they were pollinated. The germination figures show that darkness does not favour the receptivity of the stigma. Seed-setting trials confirmed the above experience.

TABLE XIX

(*a*) *Effect of light on the receptivity of stigma*

(In darkness for 15 hours prior to pollination)

Treatment	Number of pollen grains on the stigma		Percentage of germination
	Sown	Germinated	
Light	2,024	1,880	92·8
„ (duplicate)	2,146	1,941	90·4
Darkness	1,964	857	43·4
„ (duplicate)	2,007	989	49·2

(*b*) *Effect of light on stigma and the resultant seed-setting*

(In darkness for 24 hours prior to pollination)

Treatment	Number of flowers emasculated and pollinated	Number of seeds set	Percentage of seed settin
Light	36	22	61·1
Darkness	33	5	15·1

Though the largest anthesis is as early as 2 A. M., when the mass of liberated pollen escapes the devastating influences of desiccation and gets an assured lodging in the stigmatic feathers, the optimum germination of such pollen gets deferred to daybreak and the availability of light. This definite differential behaviour in the receptivity of the stigma passed through darkness raises the interesting question of the delicacy of response to light even of so weak an intensity as that of the moon's.

Pollen-prepotency.—The differences in the size and colour of pollen in sorghum are not marked enough to effect a pollination with a combination of different kinds of pollen and test pollen-prepotency on the same stigma. It was, therefore necessary to emasculate and dust two different sets of flowers on the same panicle. One set was dusted with its own pollen and the other with foreign pollen.

TABLE XX

(*a*) *Pollen-prepotency—Pollen germination*

	Number of pollen grains on the stigma		Percentage of germination
	Sown	Germinated	
Own pollen (from yellow grained variety) .	1,834	1,259	68·1
Own pollen (from yellow grained variety) (duplicate).	2,018	1,486	73·6
Foreign pollen (from red grained variety) .	2,006	1,846	93·0
Foreign pollen (from red grained variety) (duplicate).	2,214	2,076	93·3
Foreign pollen (from white grained variety) .	1,905	1,737	90·6
Foreign pollen (from white grained variety) (duplicate).	2,322	2,194	94·4

(*b*) *Pollen-prepotency—Seed-setting*

	Number of flowers emasculated and pollinated	Number of seeds set	Percentage of seed-setting
Own pollen (from yellow grained variety).	35	17	48·6
Foreign pollen (from red grained variety).	30	20	66·6
Foreign pollen (from white grained variety).	43	27	62·8

It will be seen that foreign pollen is favoured.

Varietal differences in receptivity.—Stigma-receptivity in various varieties was tried both for pollination and seed-setting. Two sets of ten plants from a variety were chosen. Pollen was dusted (after emasculation) to flowers on one plant every day. In one set the stigmas were killed eight hours after dusting and the other was allowed to set seed.

TABLE XXI

(a) Receptivity of stigma in varieties—pollen germination

Variety	Number of pollen grains on the stigma		Percentage of germination
	Sown	Germinated	
S. durra (var. *Tella Jonna*)—			
Stigmas 24 hours old . . .	3,464	2,970	85·7
„ 48 „ „ . . .	3,349	2,690	70·3
„ 72 „ „ . . .	6,088	1,072	17·6
„ 96 „ „ . .	5,298	1,541	29·1
„ 120 „ „ . . .	1,784	633	35·4
„ 144 „ „ . . .	2,171	703	32·3
S. durra (var. *Peria Manjal*)—			
Stigmas 24 hours old . . .	11,426	10,322	90·3
„ 48 „ „ . . .	11,526	10,962	95·1
„ 72 „ „ . . .	1,477	742	50·2
„ 96 „ „ . . .	1,724	938	54·4
„ 120 „ „ . . .	1,656	*Nil*	*Nil*
S. roxb. var. *hians* (var. *Talaivirichan*)			
Stigmas 24 hours old . . .	2,414	2,121	87·8
„ 48 „ „ . . .	697	336	48·2
„ 72 „ „ . . .	557	231	41·4
„ 96 „ „ . . .	124	49	39·5
„ 120 „ „ . . .	321	*Nil*	*Nil*

TABLE XXI—*contd.*

(b) Receptivity of stigma in varieties—seed-setting

Variety	Number of flowers emasculated and pollinated	Number of seeds set	Percentage of seed-setting
S. roxb. var. *hians* (var. *Talaivirichan*—duration 150 days)—			
Stigmas 24 hours old . .	35	26	74·3
„ 48 „ „ . .	37	15	40·5
„ 72 „ „ . .	29	13	45·0
„ 96 „ „ . .	33	3	9·0
S. durra. (var. *Peria Manjal*—duration 145 days)—			
Stigmas 24 hours old . .	99	41	41·4
„ 48 „ „ . .	63	26	41·3
„ 72 „ „ . .	45	13	29·0
„ 96 „ „ . .	57	12	21·0
S. durra. (var. *Chitrai Vellai*—duration 115 days)—			
Stigmas 24 hours old . .	59	33	56·0
„ 48 „ „ . .	69	30	43·5
„ 72 „ „ . .	60	11	18·3
„ 96 „ „ . .	57	4	7·0
„ 120 „ „ . .	59	2	3·4
S. durra. (var. *Chinna Manjal*—duration 105 days)—			
Stigmas 24 hours old . .	84	53	63·1
„ 48 „ „ . .	82	52	63·4
„ 72 „ „ . .	42	11	26·2
„ 96 „ „ . .	99	7	7·4
„ 120 „ „ . .	177	14	7·9
S. durra. (var. *Vellai Cholam*—duration 95 days)—			
Stigmas 24 hours old . .	24	17	70·8
„ 48 „ „ . .	31	21	67·7
„ 72 „ „ . .	32	2	6·1
„ 96 „ „ . .	24	1	4·2

It will be noted that seed sets in stigmas that are forty-eight hours old after which there is only a weak setting leading to none on the sixth day. The experiences of Stephens and Quinby [1934] in which they record receptivity up to sixteen days is, therefore, a great divergence from this South Indian experience. It will be seen that the duration of a variety did not affect the duration of the receptivity of its stigma.

In a healthy stigma, the feathers are turgid and stand at right angles to the axis—which is a sign of their receptivity. Before the opening of the flower, they are not turgid and remain adpressed to the axis. Under adverse conditions—like disease, etc.,—the feathers are flaccid and have a withered look.

Conclusion.—The foregoing data show that darkness and humid conditions impair the viability of the pollen and the receptivity of the stigma. Low temperatures favour the receptivity of the stigma and the germination of pollen. Desiccation quickly kills the pollen but has no effect on stigma-receptivity. Sorghum is wind-pollinated and well adapted to arid rigions; the stigma provides a large surface area to catch the pollen and suitable substratum for its germination (and protection from desiccation). The pollen and stigma are both delicate structures. The details of their delicate response to their environment show that a fine equipoise between the ability of the pollen to germinate and the stigma to be receptive has been achieved. A careful examination of the sorghum stigma showed no fluid excretions nor does it exert any tropistic influence. The role of the stigma, therefore, seems to be to maintain optimum moisture conditions for pollen germination.

Summary

In sorghum the anthers vary in size but not in shape. The commonest cultivated varieties possess the biggest anthers. The pollen grains also vary in size and roughly parallel anther-size differences. "Dummy pollen" is peculiar to sorghum. It occurs in *Pennisetum typhoideum* also. Its incidence and functions are detailed. It is found that its incidence in numbers large enough to ensure anther opening, is a simple dominant to poor incidence leading to non-dehiscence and sterility.

Sorghum pollen is highly sensitive to the medium in which it is grown. Forty-one per cent sucrose with 0·75 (summer) and 1·5 (winter) per cent shred agar is found to be the best medium for the artificial germination of pollen. Germinations are better on cloudy, humid days than on hot, dry days. Considerable variation is found in the germination percentage of cultivated varieties. Compared with the night-flowering varieties, the day-flowering variety gave a much higher germination percentage. Pollen from staminate flowers has a distinctly lower percentage of germination and the tube length is comparatively shorter. Though pollen germinates from 2—10 A. M., best germinations are obtained from material between 7 A. M. and 8 A. M. Low temperatures have a distinctly beneficial effect on pollen germination. Up to 40°C. the germination is fairly good but beyond that there is a sudden drop in germination. Darkness inhibits the germination of pollen. The pollen grain has a tube nucleus and two generative nuclei. In *S. margaritiferum* and *Andropogon annulatus*, the nuclei are spindle-shaped. In *S. durra* they are larger and more elongated. In the initial stages, the pollen-tube from the pollen of staminate flowers grows slower than that in bisexual flowers. To attain its maximum length, the pollen-tube takes three to four hours in artificial

cultures. Under saturated conditions for forty-eight hours, twenty-eight per cent of the pollen remains viable. Pollen is capable of fertilising up to the third day though in a very weak measure (21 per cent).

Stigmas have the shape of truncated spindles. Two types of stigmas—a brush-like common one and a bushy one characteristic of *S. roxb.* var. *hians.* and *S. nervosum*—are met with. The germination of pollen on stigmas is very high. Stigma-receptivity is impaired by rise of temperature or humidity and darkness inhibits it though desiccation of the atmosphere does not seem to affect it. Seeds set in stigmas that are forty-eight hours old after which there is only a weak setting leading to none on the sixth day. The percentage of setting decreases with the age of the stigma. The duration of a variety does not seem to influence the duration of the receptivity of its stigma. The role of the stigma seems to be primarily to maintain optimum moisture-conditions for pollen germination.

REFERENCES

Patel, M. L. and Patel, G. B. (1929). *Mem. Dep. Agric. Ind.* (*Bot. Series*) **16**, 1-58.

Rangaswami Ayyangar, G. N. and Panduranga Rao, V. (1931). *Ind. J. Agric Sci.* **1**, 445-454.

———————————(1935). *Curr. Sci.* **3**, 540-543.

———————————(1935). *Curr. Sci.* **4**, 315.

Stephens, J. C. and Quinby, J. R. (1934). *J. Agric. Res.* **49**, 123-136.

BLIGHT AND HOLLOW-STEM OF SORGHUM

BY

B. N. UPPAL,

Plant Pathologist to the Bombay Government,

K. G. KOLHATKAR,

Formerly Assistant Mycologist, Bombay Department of Agriculture,

AND

M. K. PATEL,

Assistant Professor of Mycology, College of Agriculture, Poona

(Received for publication on 26th June 1935)

(With Plates LXIX-LXXII and one text-figure)

Rhizoctonia bataticola (Taub.) Butler, or its pycnidial stage *Macrophomina phaseoli* (Maubl.) Ashby, has a very wide host range, yet so far this fungus has not been reported to cause disease in *jowar*, *Andropogon sorghum*. In 1930 [Uppal, 1931] *jowar* plants in many fields in the neighbourhood of Broach in Gujarat were observed to show signs of early maturity, and on closer examination were found to have become stiff and dried up. When stalks of such plants were split open, the pith and fibres were found studded with numerous black sclerotial bodies. In the following year a seedling blight of *jowar* appeared in an epidemic form in East Deccan following periods of heavy late rains and high temperatures, and the diseased plants also exhibited the general symptoms of drying and premature ripening. It seems very probable, however, that the disease has existed in the Bombay Presidency for many years, although it has not so far been reported elsewhere in this country. Recently Mackie [1932] has described a similar disease in maize from California.

The disease

The disease is common in *rabi jowar* on the *bhata* soils along the Nerbudda river in Broach and near Mohol in East Deccan. The *bhata* soils are sandy loam to silt loam and are formed every year by the deposition of silt and other fine material brought with flood waters during the monsoon. They are deficient in humus and have low power of retaining moisture. The soils in East Deccan, however, are medium black and are retentive of moisture.

Infection in *kharif jowar* has never been observed as evidently the environmental conditions during the monsoon are not favourable. The seriousness of the disease in *rabi jowar*, however, is greatly modified by the character of the

season in any particular year, infection becoming general when heavy rains and high temperatures are experienced in October or early November. In such years seedling blight is very common in East Deccan, resulting in irregularity of stand and subsequent reduction in yield. Observations during the past five years have shown that the disease is, on the whole, of sufficient economic importance.

Symptoms.—Generally there is no external evidence of the disease until the plant approaches maturity. At this time infected plants show premature ripening, but the ear-heads are poorly developed (Pl. LXIX, fig. A). The stalks are weak as they are hollow inside, and may break under the force of strong wind. These stalks are easily shaken by wind and, as they strike against each other, they produce a sound somewhat reminiscent of the beating together of hollow, dry sticks, and hence the disease is aptly called *khadkhadia* in Broach.

When the infected stalk is split open, numerous black bodies are seen clustered round the fibrovascular bundles and in the medulla or pith ; they are not present in the inner cortex. These small bodies are the sclerotia of the fungus and are found for considerable distances up in the stem and down in the roots (Pl. LXIX, fig. B1). The development of the sclerotial bodies in the pith causes this tissue to disintegrate, resulting in the longitudinal splitting of the internal tissue along the bundles into masses of fibres (Pl. LXIX, fig. B2). The development of sclerotia on the fibrovascular bundles interferes with the normal movements of water and food materials in the plant, resulting in premature ripening and shrivelling of grains in poorly developed ears (Pl. LXIX, fig. C). The disintegration of medulla or pith, on the other hand, weakens the plant which may break under the force of wind.

The fungus enters the plant through small feeding roots and ascends the stem for considerable distances and in some cases may be traced up to the ear-head. In the earliest stage of the disease the cortical tissue at the collar has a flaccid appearance, later turns reddish brown and ultimately rots away. If environmental conditions may turn out very favourable in the early stage of attack, seedling blight becomes very destructive, and the cultivator attributes depletion in stand to poor germination or to hot weather injury.

Inoculation experiments

Numerous isolations have been made from diseased *jowar* plants collected in widely separated localities, and in all cases a fungus has been obtained that on potato-dextrose agar produces mycelium similar to that of *Rhizoctonia*, and later forms black sclerotia and in some strains also produces pycnidia containing pycnospores. This fungus is indistinguishable from *Macrophomina phaseoli* (Maubl.) Ashby, the pycnidial stage of *Rhizoctonia bataticola* (Taub.) Butler, which is commonly isolated from cotton plants suffering from the so-called root-rot.

FIG. A. *Left.* An ear-head from an infected plant. *Right.* A normal ear-head.

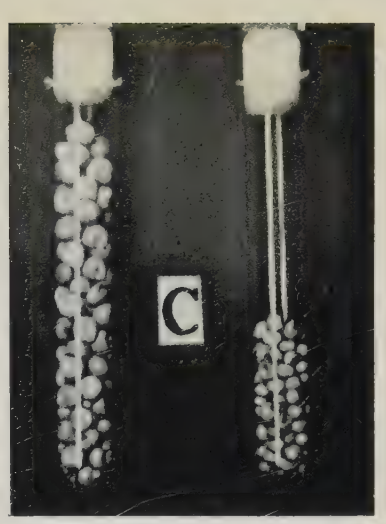


FIG. C. *Left* 100 seeds from a normal ear-head. *Right.* 100 shrivelled and poorly developed seeds from a diseased ear-head.

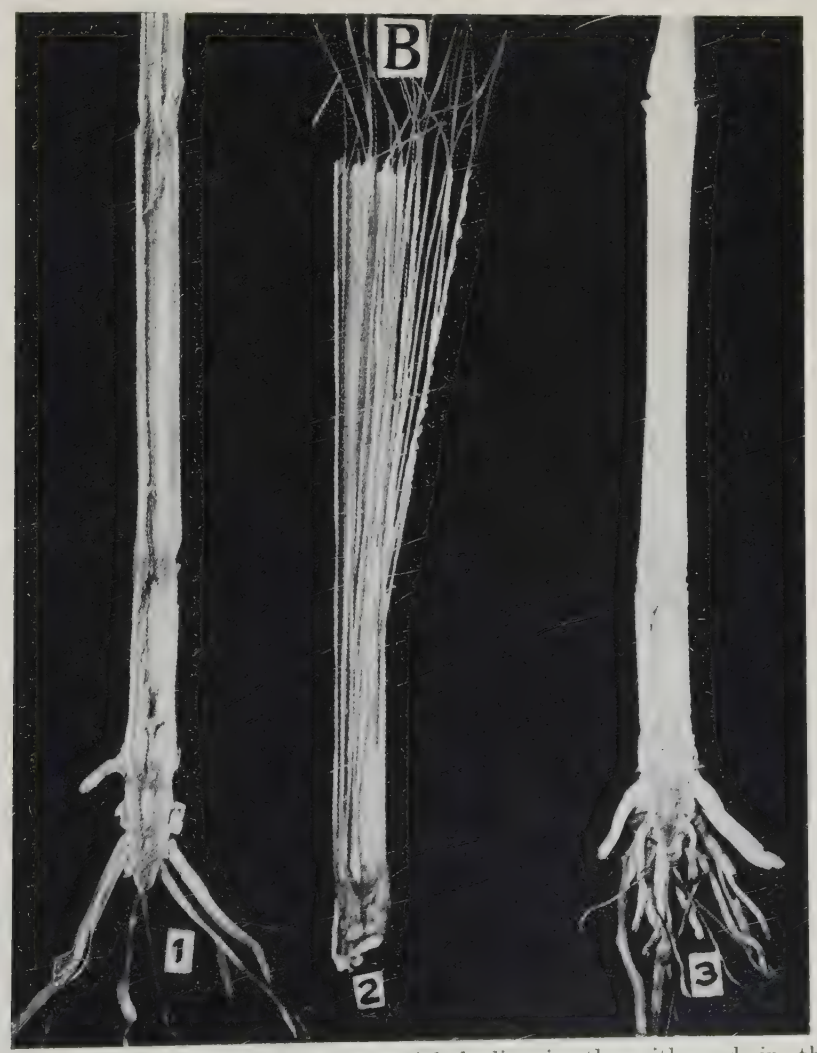


FIG. B. (1). A diseased plant showing sclerotial bodies in the pith and in the roots; (2) Disintegration of pith and separation of vascular bundles. Sclerotia are attached to bundles; (3) A healthy stalk split open.

FIG. 1. Healthy seedlings.

FIG. 2. Artificially infected seedlings showing browning of the stem at the collar.

In order to test its pathogenicity, the fungus (Broach strain, *i.e.*, the isolate of *Macrophomina phaseoli* from Broach) was multiplied on Richard's agar in giant Erlenmeyer flasks, and the resulting mycelial growth was uniformly mixed with sterilised river soil, which was then put into large glazed containers. *Jowar* was sown in these containers ; four weeks after sowing the seedling plants were examined, and six out of twenty plants showed root infection and browning of the stem at the collar (Pl. LXX, fig. 2) and gave a pure culture of the fungus on isolation. The control plants remained healthy.

In another test *jowar* plants were grown in Knop solution in Roux tubes, and small bits of agar culture of the fungus (Broach strain and Mohol strain, the latter being an isolate from Mohol) were placed on cotton wool close to the roots. The tubes were incubated at 30 to 35° C. In a few days the seedlings collapsed, the roots turned brown, and numerous small black bodies appeared in the stem and roots. Microscopic examination of these plants showed that, in addition to sclerotial bodies, pycnidia were also produced by Mohol strain. Control plants remained healthy. The results are recorded in Table I.

TABLE I

Macrophomina phaseoli *pathogenic on* jowar *plants grown in Roux tubes*

Fungus	No. plants inoculated	Per cent of infection	Remarks
Broach strain . .	6	100	Sclerotia produced
Mohol strain . . .	6	100	Sclerotia and pycnidia produced
Control	8	0	Plants healthy

Effect of soil-temperature on infection.—Field observations indicated that *Macrophomina* disease in *jowar* usually becomes serious during and after periods of high temperatures. Experiments were, therefore, made to determine the relation of soil-temperature to infection. The results of one of these experiments are described below.

Inoculum was prepared by growing the fungus (Broach strain) on Richard's agar, and a definite quantity of it was added to sterilised soil in each galvanised iron container. Temperatures ranging from 20 to 40° C. were maintained constant in Soil Temperature Tanks of Wisconsin type. *Jowar* plants were grown in the containers at different soil-temperatures for six weeks, after which period the containers were removed to a glasshouse and plants allowed to grow to maturity under ordinary conditions. After the plants had produced ear-heads, they were split open and the presence or absence of sclerotial bodies in the stem and roots was noted in each case. Control plants were grown at each temperature and were similarly treated except that no inoculum was added to the soil. The results are summarised in Table II.

TABLE II

Relation of soil-temperature to infection of jowar

Soil-temperature (°C.)	No. plants exposed to infection	Per cent of infection
20·0 . . .	34	0·0
30·0 . . .	35	0·0
33·0 . . .	28	7·1
35·5 . . .	19	36·8
37·5 . . .	23	13·0
40·0 . . .	25	0·0

It will be seen from Table II that 35·5° C. is the optimum temperature of infection, which falls off appreciably below and above this level. At 30° C. and below no disease developed in plants which made normal growth. There was also no infection at 40° C., but plants suffered from the effects of high temperature and made poor growth. Seedling blight occurred at 35·5° and 37·5° C., but this type of injury was not common at 33° C. In all cases control plants remained healthy and produced normal ear-heads.

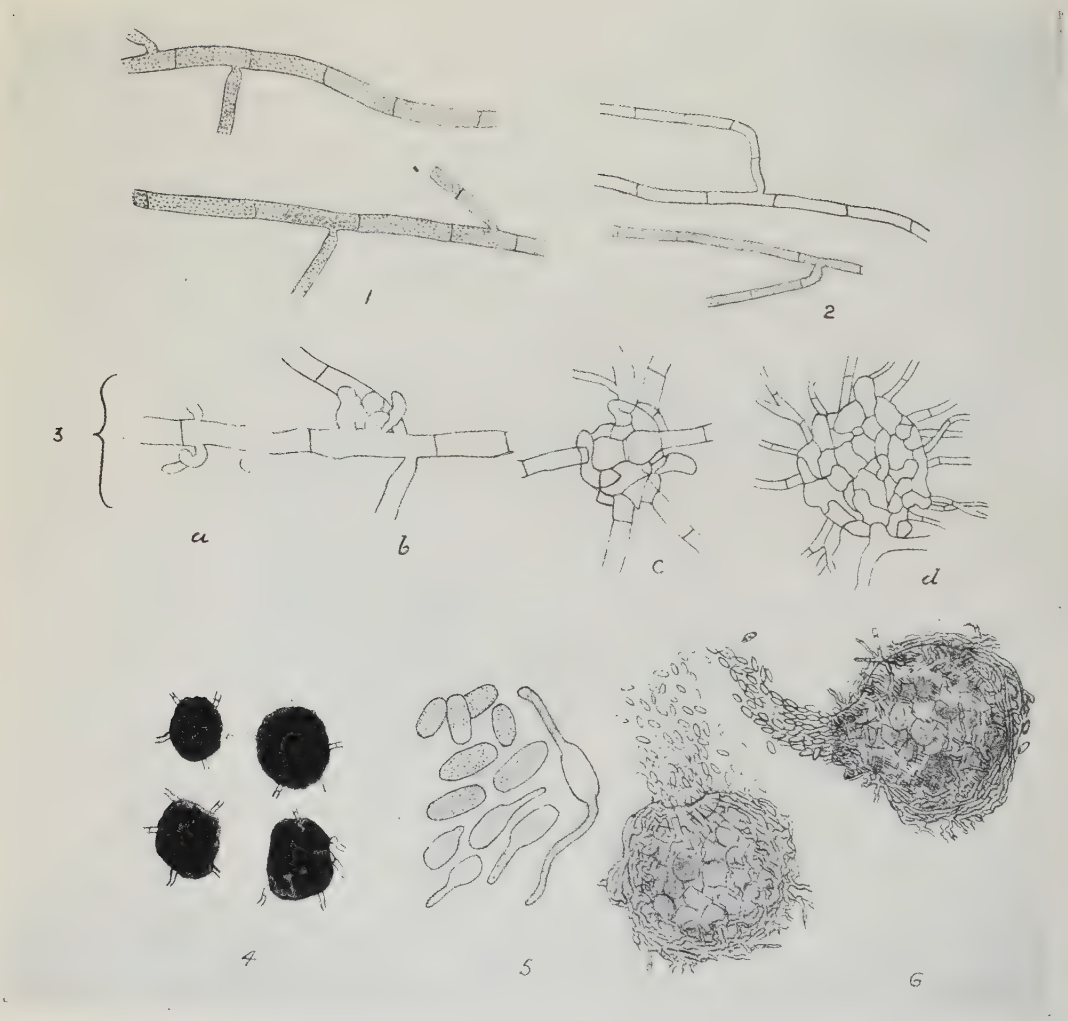
Effect of soil-moisture on infection.—Experiments were further made to determine the relation of soil-moisture to infection in correlation with optimum soil-temperature (35° C.). These experiments included a range of soil-moistures from twenty to sixty-five per cent based on the water-holding capacity of the soil. All plants were grown in different soil-moistures in Soil Temperature Tanks for six weeks and then grown to maturity under ordinary conditions. The results are recorded in Table III.

TABLE III

Relation of soil-moisture to infection of jowar

Water-holding capacity of soil	No. plants exposed to infection	Per cent of infection
20 . . .	11	0·0
30 . . .	11	0·0
40 . . .	11	0·0
50 . . .	9	0·0
65 . . .	9	33·3

It will be seen from Table III that high amounts of moisture in the soil are favourable to infection, the fungus becoming completely inactive in fifty per cent



FIGS. 1. Young hyphae of *Macrophomina phaseoli* colourless and full of protoplasm showing characteristic branching. (×560). 2. Old hyphae thin and with little or no protoplasm. (×560). 3. *a-d* Successive stages in the formation of sclerotia. (×560). 4. Black, carbonaceous sclerotia. (×150). 5. Showing range of size and shape of conidia. Also germinating conidia. (×560). 6. Pycnidia with a truncate ostiolum, and conidia. (×110).

water-holding capacity of the soil or lower moisture-content. Since soil-moisture is generally below the favourable level of infection under the normal range of field conditions during the *rabi* season in East Deccan, high temperatures alone do not seem to be sufficient to induce infection under conditions of low soil-moisture content. Soil-temperature and soil-moisture are thus the limiting factors, the fluctuations of which determine the occurrence and severity of infection of *jowar*. These results confirm the common observation that the disease is prevalent in *rabi jowar* following periods of heavy rains and high temperatures. In years when no late rains are received, the disease does not appear in East Deccan although soil-temperature in October and early November is generally favourable to infection.

It is also the general observation that clayey soils are more favourable to infection because of their ability to retain moisture, than loose sandy loams. In an experiment *jowar* plants were grown in clay and sandy loam at 35° C., and to these equal quantities of inoculum were added. The results in Table IV show that the percentage of infection in clayey soil is much higher than in sandy loam.

TABLE IV

Effect of type of soil on infection of jowar

Type of soil	No. of plants in test	Per cent of infection
Sandy loam . . .	20	10
Black soil (clay) . . .	20	85

MORPHOLOGICAL CHARACTERS OF THE FUNGUS

The morphological characters of *Macrophomina phaseoli* vary with the age of culture. When young, the hyphae are colourless and full of dense protoplasm ; they average about 8μ in diameter. Their branching is characteristic ; the branches lie almost parallel to the main hypha and are constricted at the point of union ; a wall is laid down a short distance from this point (Pl. LXXI, fig. 1). With age the hyphae become thin, brown and vacuolate, the lumen ultimately containing little or no protoplasm. The branches then lie almost at right angles to the main hypha (Pl. LXXI, fig. 2).

In young cultures the sclerotia become visible in forty-eight to seventy-two hours at about 27° C. They are formed from a hypha the cells of which repeatedly divide giving rise to masses of irregular and barrel-shaped cells. Secondary

branches arise and curl round one another so that a minute sclerotium is formed. These bodies rapidly grow and soon become black and carbonaceous (Pl. LXXI, fig. 4). A few stages in the formation of sclerotia are shown in the plate (Pl. LXXI, fig. 3 *a-d*).

Both Mohol and Broach strains form sclerotia freely on potato-dextrose agar and also show concentric zoning in plate culture (Pl. LXXII, fig. A). Saltations may arise spontaneously, and Plate LXXII shows a sterile form produced by Mohol strain, in which mycelium is submerged instead of aerial (Pl. LXXII, fig. B). The range of sclerotial size of Broach and Mohol strains is given in Table V.

TABLE V

Diameter of sclerotia of Macrophomina phaseoli

Fungus	Range	Mean
Broach strain . . .	40—220μ	130μ
Mohol strain	40—180μ	110μ

It will be seen from the table that Broach and Mohol strains have a mean sclerotial diameter of 130μ and 110μ respectively. Haigh [1930] has divided different strains of *Macrophomina phaseoli* into A, B and C groups on the basis of the mean sclerotial diameter in culture. According to this classification both Broach and Mohol strains fall in the C group having small sclerotia with a mean sclerotial diameter of about 120μ or less, although the upper limits of the range of sclerotial measurements, particularly of Broach strain, overlap the lower end of Haigh's B group having a mean sclerotial size of about 200μ.

Pycnidia are freely produced by Mohol strain on *jowar* seedlings grown in Roux tubes with Knop solution, but have never been observed in Broach strain. They are blackish brown with a truncate ostiolum and measure from about 150 to 290μ in diameter (Pl. LXXI, fig. 6). The pycnospores are mostly oval or elliptical in shape, hyaline, continuous and with a thin wall ; the content is finely granular (Pl. LXXI, fig. 5). In size they vary from 10 to 24μ × 6 to 10μ, mostly 14 to 20μ × 6 to 8μ ; these measurements agree with those given by Ashby [1927] for the fungus, although the conidia on *jowar* are somewhat smaller in length. In germination the conidia produce one or more germ-tubes (Pl. LXXI, fig. 5).

CULTURAL CHARACTERS OF THE FUNGUS

Growth at different temperatures.—The effect of temperature on the rate of growth of Broach and Mohol strains on Richard's agar was studied. Each strain

FIG. A. Cultures of Broach strain of *Macrophomina phaseoli* on potato-dextrose agar showing concentric zoning.

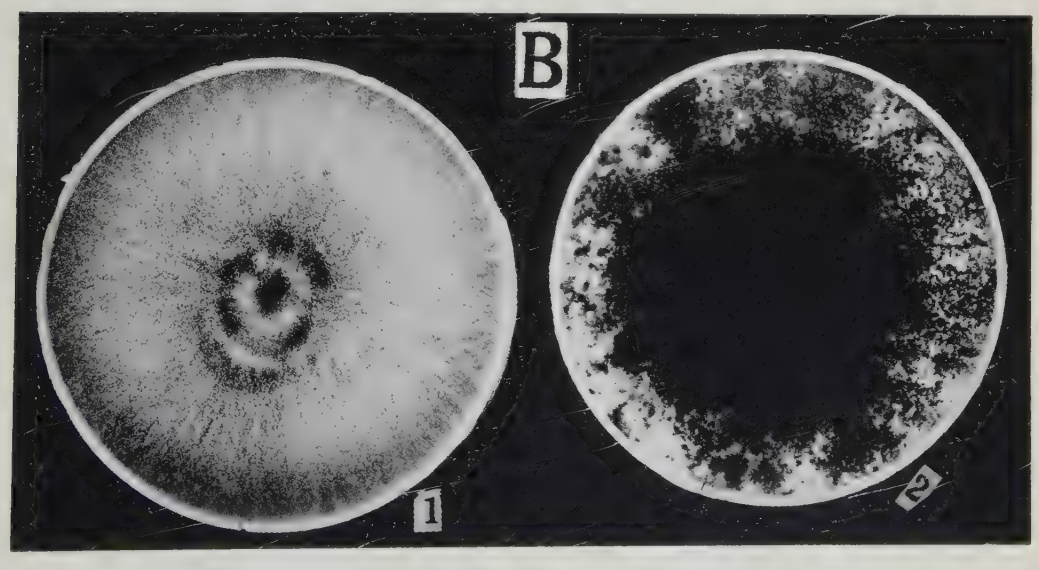


FIG. B. (1). Normal culture of Mohol strain showing aerial mycelium and sclerotia : (2) Sterile saltant on potato-dextrose agar showing submerged dark strands of hyphae.

was grown in duplicate at different temperatures. Measurements of colony diameter were made daily for seven days ; but at optimum temperatures the fungus growth covered the whole plate at the end of three days. The curves showing graphically the rate of growth of the two strains at different temperatures at the end of three days are given in Fig. 1.

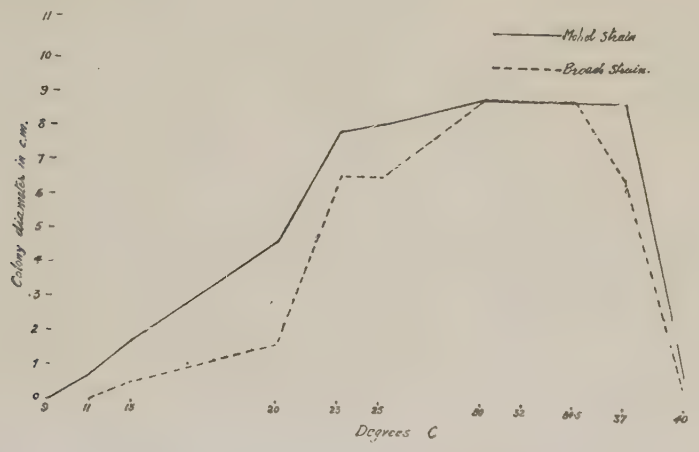


Fig. 1. Relation of temperature to radial growth of *Macrophomina phaseoli*.

In general, the two strains have about the same rate of growth at different temperatures, although Mohol strain grows faster than Broach strain. The optimum temperature of Broach strain lies between 30 and 34·5° C. and of Mohol strain between 30 and 37° C. ; at higher levels the radial growth of the two strains falls off sharply. The fungus also makes very slow growth at lower temperatures. Whilst Mohol and Broach strains made no growth at 9° and 11° C., respectively, at the end of two days, they had made slight growth after five days. At lower levels, however, growth was completely checked. At 40° the two strains make feeble growth in the beginning, but at the end of seven days colonies of Mohol strain measured 3·9 cm. in diameter, and those of Broach strain were hardly 1·9 cm.

Growth in liquid media.—A series of flasks was set up containing 500 c.c. quantities of each of the seven synthetic liquid media. The flasks were inoculated with Broach and Mohol strains and incubated at 30 to 32° C. ; duplicate tests were run in each case. At the end of fifteen days the cultures were filtered and the mycelial mats were washed and dried between blotting paper and then over calcium chloride *in vacuo* for a week. The mats were finally weighed (Table VI).

TABLE VI

Dry weight of mycelial mats of Broach and Mohol strains

Culture medium	Dry weight of mat in grms.		Remarks
	Broach strain	Mohol strain	
Meyer	3·430	4·140	Many sclerotia
Czapek	3·310	3·865	,,
Richard	2·900	3·380	,,
Pfeffer	2·257	3·140	,,
Fermi	0·510	1·410	Few sclerotia
Coons	0·640	0·840	,,
Cohn	0·290	0·620	Very few sclerotia

It will be seen that the two strains grow very well in Meyer's solution, forming an abundance of sclerotial bodies. Czapek's, Richard's and Pfeffer's solutions were also very suitable for growth and sclerotial formation. In Fermi's and Coons' solutions, however, the two strains make very poor growth, and the number of sclerotia formed is also very small. Cohn's solution seems to be the least suited both for growth and sclerotial formation. It appears that vigorous mycelial growth induces abundant sclerotial formation.

Broach strain does not grow as well as Mohol strain in different liquid media.

Growth on solid media.—Five solid media were tested. Equal quantities of each medium were poured deep in Petri dishes. All media were inoculated in duplicate with the two strains, and plates were incubated at 30-32° C. Measurements of colony diameter were made for seven days, but as the fungus growth covers the surface of plates in four days in some cases, figures of four days' growth only are recorded in Table VII.

TABLE VII

Growth of Broach and Mohol strains on solid culture media

Culture medium		Colony diameter in cm. after days			
		1st	2nd	3rd	4th
Quaker oats agar	M*	1·2	**4·2	7·2	9·0
	B	1·0	4·0	6·5	8·5
Potato-dextrose agar	M	0·5	2·2	**5·5	7·5
	B	1·0	2·5	4·5	6·0
Corn-meal agar	M	2·0	4·2	**6·2	9·0
	B	1·5	3·0	4·0	4·5
Richard's agar	M	0·0	0·2	**2·0	4·2
	B	0·2	1·2	2·5	5·0
Brown's agar	M	0·5	2·2	4·5	5·5
	B	0·5	1·7	3·7	4·5

* "M" stands for Moho' strain and "B" for Broach strain.
** First appearance of sclerotial bodies.

It will be seen from the table that, except on Richard's agar, Mohol strain grows faster than Broach strain. Quaker oats agar promotes good mycelial growth, and sclerotia appear in culture on the second day after inoculation. Sclerotia are also formed freely on potato-dextrose agar, corn-meal agar and Richard's agar, but do not appear until the third day after inoculation. On Brown's agar, however, no sclerotia were observed even until the ninth day after inoculation.

Growth in nutrient broth in relation to H-ion concentration.—Broach and Mohol strains were grown in nutrient broth adjusted to different reactions at 30-32° C. After fifteen days the dry weight of mycelial mats was determined and is shown in Table VIII.

TABLE VIII

Growth of Broach and Mohol strains in nutrient broth at different pH

*p*H	Dry weight of mat in mgrms.	
	Broach strain	Mohol strain
2·6	4	3
3·4	117	110
4·5	118	129
5·4	113	115
6·4	75	67
7·4	46	60
8·3	43	32
9·4	49	29
10·4	19	32
11·4	4	11
12·4	2	0

The two strains can tolerate a wide range of H-ion concentrations, whilst the range of optimum reaction appears to lie between *p*H 3·4 and 6·4, indicating that acid reactions favour growth of the fungus. Sclerotia are formed in culture at all reactions, but they are more numerous in acid than in alkaline reactions.

Growth on Dox's agar in relation to H-ion concentration.—Dox's agar was made up and adjusted to different *p*H values by the colorimetric method. Before pouring into plates, a suitable indicator-dye was added to each set of the medium. The two strains were then grown on the medium, and after incubation at 30-32°C., the plates were examined after every twenty-four hours for four days to note the colour changes in the medium below the fungus colonies. Thus, if a small amount of the fungus culture is transferred to a plate of Dox's agar of *p*H 12·4 and containing sterile cresol red, the colour of the medium below the colony turns slightly yellow after two days, indicating acid-production and a shift in reaction to about *p*H 8. Measurements of colony diameter are recorded in Table IX.

TABLE IX

Growth of Broach and Mohol strains on Dox's agar at different pH

*p*H		Colony diameter in cm. after days		
		1st	2nd	4th
2·6	M*	2·0	6·9	9·0
	B	1·6	4·2	8·5
3·4	M	2·7	7·2	9·0
	B	1·8	4·8	9·0
4·5	M	2·7	7·2	9·0
	B	2·0	5·0	9·0
5·4	M	2·8	7·1	9·0
	B	2·1	5·1	9·0
6·4	M	2·7	7·0	8·7
	B	2·0	4·5	8·7
7·6	M	2·1	6·8	8·9
	B	1·8	4·0	8·7
8·6	M	2·2	7·0	8·9
	B	1·7	4·0	8·6
9·6	M	2·3	6·6	8·9
	B	1·6	3·7	8·5
10·4	M	2·5	6·3	8·9
	B	1·6	3·2	8·2
11·4	M	2·3	5·9	8·5
	B	0·8	3·0	8·3
12·4	M	2·0	5·2	7·3
	B	0·6	2·9	6·4

* "M" stands for Mohol strain and "B" for Broach strain.

It will be seen that, as in the case of nutrient broth, the optimum reaction for the growth of the two strains (after 48 hours) appears to lie between *p*H 3·4 and 6·4. At the end of ninety-six hours, however, there was little or no difference in the rate of growth on Dox's agar at different reactions due to progressive change towards acidity of the more alkaline media. Sideris [1929] has shown that "acidic substances may be formed during metabolic activities at *p*H values above that of the isometabolic point of the substance concerned, and basic substances may be formed below this point". The rapid changes in *p*H value

induced in the agar substratum, however, may be due to lesser diffusion of the metabolic products of the organism in the solid than in the liquid medium, and this may explain the result that the growth on Dox's agar is practically normal after ninety-six hours at such higher *p*H values as *p*H 10·4 to 12·4. In acid reactions mycelial growth is aerial and fluffy, becoming more and more flat as the reaction shifts towards alkalinity. Sclerotia are not formed in highly alkaline or highly acid reactions, but are numerous between *p*H 5·4 and 6·4, their number decreasing as the medium becomes more acid or more alkaline. These results are in general agreement with those of West and Stuckey [1931] for *Macrophomina phaseoli* from cotton.

Relation of oxygen to vegetative growth.—An experiment was made to determine whether or not *Macrophomina phaseoli* can grow on culture media in the absence of free oxygen in the surrounding atmosphere. A small bit of a vigorously growing culture of the fungus was transferred to a plate of potato-dextrose agar, and the latter was then placed in a desiccator. For the elimination of oxygen from the desiccator, an alkaline solution of pyrogallol was used, which was prepared with one gram of pyrogallol and 10 c.c. of ten per cent potash-water for every 100 c. c. of air space [Smith, 1905].

The desiccators were incubated at room temperature for one month, but no growth was observed in the plates. However, when the plates were removed from the desiccators, distinct signs of growth were visible after two days. In another test the fungus was still viable after the plates had been in an oxygen-free atmosphere for two months. These results indicate that *Macrophomina phaseoli* can lie dormant in poorly aerated soils and may resume activity on the return of favourable conditions.

Summary

Macrophomina phaseoli is shown to be responsible for a seedling blight and hollow-stem of *jowar*, a disease which is new to the Bombay Presidency and has not so far been reported elsewhere. The disease is common on *bhata* soils in Broach and on medium black soils in East Deccan.

The fungus enters the plant through feeding roots and ascends the stem and may be traced up to the ear-head. There is no external evidence of the disease until the plant approaches maturity. At this time infected plants are found to have hollow stalks and produce a characteristic sound as they are forcibly shaken by wind ; hence the disease has been given the name " hollow-stem ". Seedling blight is also common and may become very destructive under conditions of high soil-temperature and high soil-moisture content.

The fungus normally forms sclerotia, but Mohol strain of the fungus also produces the pycnidial stage on *jowar* seedlings grown in Roux tubes.

The disease is most active at high soil-temperature (35°C.) and high soil-moisture content, thus confirming the general experience that infection in *rabi jowar*

follows periods of heavy rains and high temperature. The disease is more common in clayey soils than in silt loams.

The morphology and cultural characters of the causative organism have been described.

REFERENCES

Ashby, S. F. (1927). *Trans. Brit. Mycol. Soc.* **12**, 141-147.
Haigh, J. C. (1930). *Ann. Roy. Bot. Gard. Peradeniya.* **11**, 213-249.
Mackie, W. W. (1932). *Phytopath.* **22**, 637-644.
Sideris, C. P. (1929). *Phytopath.* **19**, 233-268.
Smith, E. F. (1905). *Carnegie Instit. Publ.* **27**, 59.
Uppal, B. N. (1931). *Internat. Bull. Plant Protect.* **5**, 163.
West, J. and Stuckey, W. R. (1931). *Mem. Imp. Coll. Trop. Agric. Trinidad* (Mycol. Ser.) **4**, 1-20.

REVIEWS

The Cultivated Races of Sorghum. By J. D. Snowden. Printed for the Trustees of the Bentham-Moxon Fund, by Adlard and Son, Ltd., 21, Hart Street, London, W. C. 1, May 1936. Price 10s. 6d.

Spread as sorghum is, over the colonial possessions of many European nations there has been much work of an isolated type done in many places. The latest attempt at a classification of cultivated sorghum was by Dr. Stapf in 1917. He was not in possession of such valuable material as Mr. Snowden was lucky enough to deal with. Mr. Snowden has taken the commendable course of recognising the more distinct types of sorghum as definite units with the status of species. From this point of view he has given a comprehensive classification of cultivated sorghums. Under each group cultural and economic notes have been added. These help the economic botanist to appreciate the status of a variety both in his classification as well as in its economic possibilities. Clear illustrations of typical varieties help in elucidating the description of these species. A final chapter traces the relationships of the wild and cultivated sorghums. An exhaustive bibliography of over 500 references is given. Indices of botanical names, of vernacular names, and of countries and regions complete the helpfulness of this valuable publication. The Trustees of the Bentham-Moxon Fund have to be congratulated for financing the publication of this useful and thorough book. It is up to workers in sorghum in the various parts of the world to utilise this valuable publication and gain help in completing the knowledge on this important food crop. [G. N. R. A.]

Flour Milling Processes. By J. H. Scott. (Published by Messrs. Chapman & Hall, London). Pp. XV + 416, Price 21s. net.

This work by J. H. Scott does not claim any finality in its presentation of the laws governing the processes of flour milling. Prior to the publication of this book, except for "The Physical Science of Flour Milling" by Sir Ernest Simon, there has not existed any work wherein the machinery employed to mill wheat into flour has been taken step by step and its operations reduced to scientific data.

Mr. Scott has done this and also measured the extent of the effect of external influences on the operations and although the result is not perfect it is extremely valuable in itself and also as a very sound foundation, together with the above-mentioned work, for the building up of scientific literature on the subject of flour manufacture.

The need of this has been urgent for many years. Knowledge of the subject has been shrouded in a mass of guess work, confusing because of the many varying factors to be found.

The amount of exact knowledge of wheat and flour, though far from complete, has been greater than that available concerning the operations employed in converting one into the other.

Mr. Scott has gone far towards supplying the deficiency and reasons and presents his conclusions very clearly.

Pioneer work of this nature is difficult and laborious and it may be thought that too little attention has been given to some subjects and too much to others. This is almost inevitable.

Experienced millers will be familiar with the problems discussed but will find old facts presented in a more convincing way and also many new ideas. Knowledge based on hearsay and supposition is ignored or refuted. This, of course, renders the book particularly useful to students.

Especially valuable, I think, are the sections on "Behaviours of moisture in wheat", "Conditioning" and "Machine and commercial flour". All that is written on roll action is extremely interesting and well reasoned but in this the author relies more on theory—very carefully compiled theory.

The effort expended in the preparation of Section V—"The bushel weight of wheat" is to my mind rather wasted. Varying conditions are so numerous as to make this method valueless except as a rough guide.

The rest of the book maintains the high standard the author has set himself, makes very interesting reading and covers all the main mechanical and some of the bio-chemical problems to be met in flour manufacture.

Auxiliary plant and its effect of mill products is not fully treated.

The appendix with which the work concludes is very useful in parts and in parts too complex for the reviewer to offer any opinion. [H. F. M.]

THE DESTRUCTIVE INSECTS AND PESTS ACT, 1914

THE DESTRUCTIVE INSECTS AND PESTS ACT, 1914, AND THE RULES FRAMED THEREUNDER BY THE GOVERNOR-GENERAL-IN-COUNCIL FOR REGULATING THE IMPORT OF PLANTS, ETC., INTO BRITISH INDIA

Corrected up to 1st October 1936

[ACT No. II OF 1914

(*Amended up to May 1931*)

PASSED BY THE GOVERNOR-GENERAL OF INDIA IN COUNCIL

(*Received the assent of the Governor-General on the 3rd February 1914*)

AN ACT TO PREVENT THE INTRODUCTION INTO BRITISH INDIA OF ANY INSECT, FUNGUS OR OTHER PEST, WHICH IS OR MAY BE DESTRUCTIVE TO CROPS

WHEREAS it is expedient to make provision for preventing the introduction into British India of any insect, fungus or other pest, which is or may be destructive to crops ; it is hereby enacted as follows :—

Short title.

1. This Act may be called the Destructive Insects and Pests Act, 1914.

Definitions.

2. In this Act, unless there is anything repugnant in the subject or context,—

(*a*) " crops " includes all agricultural or horticultural crops, and trees or bushes ;

(*b*) " import " means the bringing or taking by sea, land or air ; and

(*c*) " infection " means infection by any insect, fungus or other pest injurious to a crop.

Power of Governor-General-in-Council to regulate or prohibit the import of articles likely to infect.

3. (1) The Governor-General-in-Council may, by notification in the Gazette of India, prohibit or regulate, subject to such restrictions and conditions as he may impose, the import into British India, or any part thereof, or any specified place therein, of any article or class of articles likely to cause infection to any crop.

(2) A notification under this section may specify any article or class of articles, either generally or in any particular manner, whether with reference to the country of origin, or the route by which imported or otherwise.

Operation of notification under section 3.

4. A notification under section 3 shall operate as if it had been issued under section 19 of the Sea Customs Act, 1878, and the officers of Customs at every port shall have the same powers in respect of any article with regard to the importation of which such a notification has been issued as they have for the time being in respect of any article the importation of which is regulated, restricted or prohibited by the law relating to Sea Customs, and the law for the time being in force relating to Sea Customs or any such article shall apply accordingly. VIII 1878.

Power of Local Government to make rules.

5. (1) The Local Government may, subject to the control of the Governor-General-in-Council, make rules for the detention, inspection, disinfection or destruction of any article or class of articles in respect of which a notification has been issued under section 3 or of any article which may have been in contact or proximity thereto, and for regulating the powers and duties of the officers whom it may appoint in this behalf.

(2) In making any rule under this section the Local Government may direct that a breach thereof shall be punishable with fine, which may extend to one thousand rupees.

Protection to persons acting under Act.

6. No suit, prosecution or other legal proceeding shall lie against any person for anything in good faith done or intended to be done under this Act.

RULES FOR REGULATING THE IMPORT OF PLANTS, ETC., INTO BRITISH INDIA

Notification No. F.-320/35-A., dated the 20th July 1936

In exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), and in supersession of the notification of the Government of India in the late Department of Revenue and Agriculture, No. 580-240, dated the 22nd June 1922, the Governor-General-in-Council is pleased to issue the following order for the purpose of prohibiting, regulating and restricting the import into British India of the articles hereinafter specified.

1. In this order—

(*i*) "Official certificate" means a certificate granted by the proper officer or authority in the country of origin; and the officers and authorities named in the 3rd column of the first Schedule appended hereto are the proper officers and authorities to grant, in the countries named in the second column, the certificates required by the provisions referred to in the first column thereof;

(*ii*) "Plant" means a living plant or part thereof but does not include seeds; and

(*iii*) "Prescribed port" means any of the following ports, namely, Bombay, Calcutta, Cochin, Dhanushkodi, Karachi, Madras, Negapatam, Rangoon and Tuticorin;

(*iv*) All provisions referring to plants or seeds shall apply also to all packing material used in packing or wrapping such plants or seeds.

2. No plant shall be imported into British India by means of the letter or sample post; provided that sugarcane for planting intended to be grown under the personal supervision of the Government Sugarcane Expert, Coimbatore, may be imported by him by such post.

3. No plant shall be imported into British India by air; provided that plants which are infested with living insects and are intended for the introduction of such living insects may be so imported if they are accompanied by a special certificate from the Imperial Entomologist to the Government of India that such plants are imported for the purpose of introducing such insects.

4. No plants other than fruits and vegetables intended for consumption, potatoes and sugarcane shall be imported into British India by sea except after fumigation with hydrocyanic acid gas and at a prescribed port:

Provided that plants which are infested with living parasitized insects and are intended for the introduction of such parasites may be imported without such fumigation if they are accompanied by a special certificate from the Imperial Entomologist to the Government of India that such plants are imported for the purpose of introducing such parasites.

Provided also that in the case of plants imported direct by Mr. M. K. Seetharama Chetty so long as he holds the post of Superintendent, Government Gardens, Mysore, such fumigation shall be dispensed with on condition that Mr. Seetharama Chetty makes himself personally responsible for the effective fumigation under the supervision of the Mycologist of the Mysore Agricultural Department

of all such plants within four days of their landing in India, and that before release from the fumigatorium the plants are certified as free from insect pests and diseases by the Government Mycologist and by the Government Entomologist, Mysore State.

Provided also that rubber plants, stumps and bud wood which the certificate required by paragraph 5 shows to have been grown in Sumatra or in the Federated Malay States and which are intended to be grown in the Tenasserim Division of Burma, may be imported without such fumigation at any port within the Tenasserim Division of Burma.

5. No plants, other than fruits and vegetables intended for consumption and potatoes, shall be imported into British India by sea unless accompanied by an official certificate in the form prescribed in the third schedule that they are free from injurious insects and diseases.

6. Potatoes shall not be imported into British India by sea unless they are accompanied by—

(*a*) a certificate from the consignor stating fully in what country and in what district of such country the potatoes were grown and guaranteeing that warty disease was not known to exist on the farms where the potatoes were grown ; and

(*b*) an official certificate that no case of warty disease of potatoes has been known during the twelve months preceding the date of the certificate within five miles of the place where the potatoes were grown.

Provided that potatoes may be imported from Italy if they are accompanied by a certificate of freedom from disease granted by a Royal Phytopathological Institute in Italy.

Provided also that potatoes may be imported under a certificate from the Imperial Economic Botanist, Imperial Agricultural Research Institute, New Delhi.

7. Rubber plants shall not be imported into British India by sea unless, in addition to the general certificate required under Rule 5 they are accompanied by an official certificate that the estate from which the plants have originated or the individual plants are free from *Fomes semitostus*, *Sphœrostible repens*, *Fusicladium macrosporum* and *Oidium heveœ*.

8. No Lemon plants, Lime plants, Orange plants, Grape-Fruit plants or other citrus plants and no cuttings of such plants shall be imported into British India unless, in addition to the general certificate required under Rule 5 they are

accompanied by an official certificate that they are free from the *Mal de Secco Deuterophoma tracheiphila* or that the disease does not exist in the country in which they were grown.

9. (1) The importation of sugarcane into British India by sea from the Fiji Islands, New Guinea, Australia or the Philippine Islands is prohibited absolutely.

(2) The importation of sugarcane into British India by sea from any other country is prohibited unless, in addition to the general certificate required under Rule 5 it is accompanied by an official certificate that it has been examined and found free from cane borers, scale insects, aleurodes, root disease (any form), pineapple disease (*Thielaviopsis paradoxa*), sereh and cane gummosis, that it was obtained from a crop which was free from mosaic disease and that the Fiji disease of sugarcane does not occur in the country of export :

Provided that in the case of canes for planting imported direct by the Government Sugarcane Expert, Coimbatore, and intended to be grown under his personal supervision, such certificates shall be required only in respect of the freedom of the country of export from the Fiji disease of sugarcane.

10. Hevea rubber plants and Hevea rubber seeds shall not be imported into British India from America or from the West Indies except by the Director of Agriculture, Madras Presidency.

11. (*a*) Seeds of flax, berseem and cotton shall not be imported by letter or sample post, otherwise than by sea.

(*b*) The importation of 'Mexican Jumping Beans' (*Sebastiania palmeri* of the family Euphorbiaceæ) is prohibited absolutely.

12. Coffee plants, coffee seeds and coffee beans shall not be imported into British India except for experimental planting purposes only by the Director of Agriculture, Madras Presidency, who shall take all measures necessary to ensure that such coffee plants, beans or seeds as are imported by him are free from plant diseases and injurious insects. Provided that the prohibition hereinbefore contained shall not apply (*i*) to roasted and ground coffee, or (*ii*) to a consignment of unroasted or unground coffee beans or seeds produced in India and covered by a certificate of origin in the form set forth in the fourth schedule appended hereto and signed by one of the authorities specified in the fifth schedule appended hereto.

13. Flax seeds and berseem (Egyptian clover) seeds shall not be imported into British India by sea, unless the consignee produces before the Collector of Customs a license from a Department of Agriculture in India in that behalf.

14. (1) Unginned cotton other than cotton from a Kathiawar port which has been produced in India shall not be imported by sea or by air.

(2) Cotton seed shall not be imported by sea save for experimental purposes by one of the officers named in the second schedule appended hereto, and shall not be so imported by such officer save at the port of Bombay and in quantities not exceeding one hundredweight in any one consignment and on condition that it will be fumigated on importation with carbon bisulphide :

Provided that, if the cotton seed is accompanied by a certificate from a Government Entomologist of the country of origin to the effect that the seed and its container have been treated in such a way as to destroy all insect life, the seed shall be examined on importation by such officer as the Governor-General-in-Council may appoint and shall not be required to be refumigated unless such examination shows that refumigation is necessary.

15. Nothing in these rules shall be deemed to apply to—

(1) the import of any article into Aden, or

(2) the bringing by sea or by air from one port or place in British India, not being in Aden, to another such port or place.

FIRST SCHEDULE [*Paragraph 1 (i)*]

Paragraph	Country of origin	Authority
1	2	3
6 (*b*)	Great Britain and Ireland .	The Ministry of Agriculture and Fisheries, England. The Department of Agriculture, Scotland. The Ministry of Agriculture, Northern Ireland. The Department of Agriculture and Technical Instruction for Ireland.
	Sweden	The Ministry of Agriculture.
	Norway	The Norwegian Board of Agriculture.
	Denmark	The Ministry of Agriculture.
	France.	Ditto.
	Japan (including Formosa) .	The Ministry of Agriculture and Forestry.
	Italy	The Ministry of Agriculture.
	Kenya Colony . . .	The Department of Agriculture.
	Australia	Chief Quarantine Officer for Plants.
	New Zealand . . .	Department of Agriculture, Industries and Commerce, Wellington.
	Holland	The Department of Agriculture.
	Germany	Ditto.
	Hungary	Royal Hungarian Service for Protection of Plants (M. Kir Novenyvedelmi Szolgalat).

Paragraph	Country of origin	Authority
1	2	3
	* Other countries	The Ministry or Department of Agriculture of the country concerned.
7	Ceylon	The Department of Agriculture.
	Malay Peninsula	The Department of Agriculture, Straits Settlements and Federated Malay States.
	Dutch Indies	The Department of Agriculture, Industry and Commerce.
	Belgian Congo	Ditto.
	Kenya Colony	The Department of Agriculture.
	Uganda Protectorate	Ditto.
	Nyassaland	Ditto.
	South Africa	The Union of South Africa, Department of Agriculture.
	Japan (including Formosa)	The Ministry of Agriculture and Forestry.
8	Italy	The Ministry of Agriculture, Royal Italian Phytopathological Institute.
	Greece	Ministry of Agriculture.
	Palestine	Department of Agriculture and Forests.
	South Africa	The Union of South Africa, Department of Agriculture.
	Northern Rhodesia	Department of Agriculture.
	Southern Rhodesia	Ditto.
	Other countries	The Ministry or Department of Agriculture of the country concerned.
9	Dutch Indies	The Department of Agriculture, Industry and Commerce.
	Mauritius	The Department of Agriculture.
	Philippine Islands	The Bureau of Agriculture.
	Japan (including Formosa)	The Ministry of Agriculture and Forestry.
	South Africa	The Union of South Africa, Department of Agriculture.
	Egypt	The Ministry of Agriculture.
	West Indies	The Imperial College of Tropical Agriculture, St. Augustine, Trinidad.
	Windward and Leeward Islands	Advisory Department of Agriculture at the Imperial College.
	British Guiana	The Department of Science and Agriculture.
	Trinidad	The Department of Agriculture.
	Jamaica	Ditto.
	United States	Ditto.
	Ceylon	Ditto.
	Malay Peninsula	The Department of Agriculture, Straits Settlements and Federated Malay States.
	Kenya Colony	The Department of Agriculture.
	Queensland	The Department of Agriculture and Stock.

* When a Customs officer receives a certificate required by clause (*b*) of rule 6 from any country not specified by name in the part of the schedule which relates to such certificate, he shall after passing the consignment forward the certificate to the Government of India, Education, Health and Lands Department, for information.

SECOND SCHEDULE [*Paragraph 14 (2)*]

The Director, Imperial Institute of Agricultural Research, New Delhi.
The Secretary, Indian Central Cotton Committee, Bombay.
The Director of Agriculture, Madras Presidency, Madras.
The Director of Agriculture, Bombay Presidency, Poona.
The Chief Agricultural Officer in Sind, Karachi.
The Director of Agriculture, Punjab, Lahore.
The Director of Agriculture, United Provinces, Lucknow.
The Director of Agriculture, Central Provinces, Nagpur.
The Director of Agriculture, Bengal, Dacca.
The Director of Agriculture, Bihar, Sabour.
The Director of Agriculture, Assam, Shillong.
The Director of Agriculture, Burma, Rangoon.
The Agricultural Officer, North-West Frontier Province, Peshawar.
The Director of the Institute of Plant Industry, Indore.
The Director of Agriculture, His Exalted Highness the Nizam's Dominions, Hyderabad.
The Director of Agriculture, Mysore State, Bangalore.
The Director of Agriculture, Baroda State, Baroda.
The Director of Agriculture, Gwalior State, Gwalior.
The Director of Agriculture and Fisheries, Travancore State, Trivandrum.
The Superintendent of Agriculture and Panchayats, Cochin State, Cochin.
The Revenue Commissioner, Porbandar State, Porbandar.
The Chief Revenue Officer, Nawanagar State, Nawanagar.
The Agricultural Research Officer, Nawanagar State, Nawanagar.
The Revenue Commissioner, Bhavnagar State, Bhavnagar.
The Revenue Commissioner, Morvi State, Morvi.
The Revenue Commissioner, Junagadh State, Junagadh.
The President of the Chamber of Agriculture, Pondicherry.

THIRD SCHEDULE (*Paragraph 5*)

Certificate

This is to certify that the plant(s), living plant(s) or plant products (*Strike out the words not applicable*) included in the consignment, of which particulars are given below were/was thoroughly examined on the (date)..... by (name).....a duly authorised official of the..... .....and found to be healthy, no evidence of the presence of any injurious insect, pest, or disease [destructive to agricultural or horticultural crops or to trees or bushes] having been found in/on them and that the consignment (including the packing) covered by this certificate has/has not been treated in the

following manner (*e.g.*, fumigated with..... .or disinfected with.....)
prior / immediately subsequent to inspection.

Inspected / Not inspected in the field by a duly authorised inspector on.....

(Signature).....

(Official status).....

Date.....

No. and description of packages.....

Distinguishing marks.....

Description of plants or plant products or parts thereof.....

Stated to be grown at.....

Exported by.....

Name and address of consignee.....

Name of vessel or particulars of route.....

Date of shipment.....

Port or place of entry.....

Additional Certificate(s) attached.....

(Give here details of any special certificate or certificates issued in respect of imports specifically scheduled).

FOURTH SCHEDULE (*Paragraph 12*)

Certificate of origin for Indian coffee beans or seeds

Name of consignor	Name of consignee	Gross weight	Number of packages	Mark of each package	Name of district in which produced

Certified that the above consignment of raw coffee beans or seeds is Indian produce grown in the district specified above.

Signature of certifying authority.

No. of Railway Receipt or
No. of Bill of Lading.

Signature of Consignor.

FIFTH SCHEDULE (*Paragraph 12*)

Certifying authority :—

(*i*) The Assistant Director of Agriculture, Chickmagalur, Kadur District, Mysore State.

(*ii*) The Director of Agriculture and Fisheries, Travancore State.

(*iii*) The Director of Agriculture, Cochin Government.

(*iv*) The Director of Agriculture, Madras Presidency.

(*v*) Any other officer whom the Government of Madras may appoint in this behalf by notification in the Fort St. George Gazette.

Notification No. 1581-Agri., dated the 1st October 1931

In exercise of the powers conferred by Sub-section (1) of Section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), hereinafter referred to as the said Act, and in supersession of the notifications of the Government of India in the Department of Education, Health and Lands, Nos. 1493, dated the 14th November 1925 and 1561, dated the 26th November 1925, and of all notifications amending the same, the Governor-General-in-Council is pleased to issue the following order for the purpose of regulating the import into British India of American cotton :—

1. In this order :—

(*i*) " Cotton " includes ginned cotton, and droppings strippings, fly and other waste products of a cotton mill other than yarn waste, but does not include cotton seed or unginned cotton.

(*ii*) " American Cotton " means all cotton produced in any part of America.

(*iii*) " Bale " means any pressed package of cotton of whatever size or density.

(*iv*) " Square Bale " means a bale of a weight exceeding 270 lbs.

(*v*) " Round Bale " means a bale of a weight not exceeding 270 lbs.

2. American cotton shall not be imported into British India by means of the letter or sample post or as passengers' accompanied baggage and shall not be imported by any other means save through the port of Bombay and subject to the following conditions :—

(*a*) On or before the departure of a ship carrying a consignment of American cotton for Bombay from the port from which the cotton is consigned, the consignee shall ascertain the name of the ship, the

probable date of its arrival in Bombay, and the number of square and round bales of American cotton contained in the consignment, and shall furnish this information to the Docks Manager of the Bombay Port Trust not less than 14 days before the arrival of the ship at Bombay : provided that where the cotton is loaded for Bombay at Port Said or at a European port, the ordinary length of voyage from which is less than three weeks, it shall be sufficient to furnish the information not less than ten days before the arrival of the ship at Bombay ;

(*b*) On arrival at Bombay, the cotton shall be disinfected in such manner as shall be prescribed in rules made by the Government of Bombay under section 5 of the said Act ;

(*c*) Prior to taking delivery of the cotton the importer shall pay a sum at the rate hereinafter provided, which shall cover the cost of fumigation, including the cost of loading the cotton into the barge, conveyance to the fumigation wharf or bunder, unloading from the barge after fumigation and delivery at the bunder, but not including docks import charges as specified in the Bombay Port Trust Scale of Rates charged at the docks :

Provided that samples of American cotton imported by parcel post or as ship's parcels, not exceeding 20 lbs. each in weight shall be fumigated free of cost in the fumigation Chamber of the Bombay Customs House ;

Provided further that the Docks Manager of the Bombay Port Trust may, in accordance with any general or special orders of the Governor-General-in-Council for the time being in force, remit or refund, in whole or in part, any sum which under this order is payable or has been paid on any consignment of American cotton ;

(*d*) No vessel shall discharge American cotton during a period of rain, mist or drizzle.

3. The rate referred to in clause (*c*) of paragraph 2 shall be Rs. 2-7-0 per square bale and Rs. 1-8-0 per round bale, or when cotton is landed at the special American Cotton wharf in the Bombay Docks Rs. 3-12-0 per square bale and Rs. 2-8-0 per round bale :

Provided as follows :—

(*i*) in cases in which the importer has failed to furnish information in accordance with clause (*a*) of paragraph 2 each of the rates hereinbefore prescribed shall be increased by Rs. 2 per bale ;

(*ii*) the minimum fee for the fumigation of any cotton imported at any one time on a single ship shall be rupees one hundred and fifty, and when such minimum fee is leviable, it shall, if there is more than one consignee, be distributed among the consignees in proportion to the amount of their respective consignments.

As amended by Government of India, Education, Health and Lands Department, Notification No. F. 398/33-A., dated 2nd April 1934 ; Notification No. F. 136/34, dated the 17th May 1934 ; Notification No. F. 190/33-A., dated the 13th August 1934 ; Notification No. 4573/34-A., dated the 24th January 1935 and Notification No. F. 34-3/34-A., dated the 4th February 1935.

PUBLICATIONS OF THE IMPERIAL COUNCIL OF AGRICULTURAL RESEARCH, INDIA

1. Agriculture and Live-stock in India

A bi-monthly Journal of Agriculture and Animal Husbandry for the general reader interested in Agriculture or Live-stock in India or the Tropics. (Established 1931. Published in January, March, May, July, September and November. Prepayable subscription Rs. 6 or 9*s*. 9*d*. per annum inclusive of Indian postage. Price per part Rs. 2 or 3*s*. 6*d*. inclusive of Indian postage). Volumes I to VI complete are available.

2. The Indian Journal of Agricultural Science

A bi-monthly Scientific Journal of Agriculture and the allied sciences, mainly devoted to the publication of the results of original research and field experiments. (Established 1931. Published in February, April, June, August, October and December. Prepayable subscription Rs. 15 or 24*s*. per annum inclusive of Indian postage. Price per part Rs. 3 or 5*s*. 3*d*. inclusive of Indian postage.) Volumes I to VI complete are available.

3. The Indian Journal of Veterinary Science and Animal Husbandry

A quarterly Journal for the publication of scientific matter relating to the health, nutrition and breeding of live-stock. (Established 1931. Published in March, June, September and December. Prepayable subscription Rs. 6 or 9*s*. 9*d*. inclusive of Indian postage. Price per part Rs. 2 or 3*s*. 6*d*. inclusive of Indian postage.) Volumes I to VI complete are available.

4. Scientific Monographs of the Imperial Council of Agricultural Research

NCAG—SM/1 — No. 1. The Fungi of India, By E. J. Butler, C.I.E., D.Sc., M.B., F.R.S. and G. R. Bisby, Ph.D. (1931). Price Rs. 6-12-0 or 11*s*. (As. 8.)

NCAG—SM/2 — No. 2. Life-histories of Indian Microlepidoptera, Second Series: Alucitidae (Pterophoridae, Tortricina and Gelechiadae), By T. Bainbrigge Fletcher, R.N., F.L.S., F.E.S., F.Z.S. (1932). Price Rs. 3-4-0 or 5*s*. 6*d*. (As. 6.)

NCAG—SM/3 — No. 3. The Open Pan System of White-Sugar Manufacture, By R. C. Srivastava, B.Sc. (1935, 2nd edition). Price Rs. 3-2-0 or 5*s*. 6*d*. (As. 9.)

NCAG—SM/4 — No. 4. Life-histories of Indian Microlepidoptera: Cosmopterygidae to Neopseustidae, By T. Bainbrigge Fletcher, R.N., F.L.S., F.E.S., F.Z.S. (1933). Price Rs. 4-8-0 or 7*s*. 6*d*. (As. 8.)

NCAG—SM/5 — No. 5. The Bombay Grasses, By E. J. Blatter, S.J., Ph.D., F.L.S. and C. McCann, F.L.S. Illustrated by R. K. Bhide. Price Rs. 20-12-0 or 32*s*. 6*d*.

NCAG—SM/6 — No. 6. Helminth Parasites of the Domesticated Animals in India, By G. D. Bhalerao, M.Sc. Price Rs. 7-12-0 or 13*s*. 3*d*.

NCAG—SM/7 — No. 7. Influence of Manures on the Wilt Disease of *Cajanus indicus* Spreng. and the Isolation of Types Resistant to the Disease, By W. McRae, M.A., D.Sc. (Edin.), F.L.S. and F. J. F. Shaw, D.Sc. (Lond.), A.R.C.S., F.L.S. (1933). Price Rs. 2-4-0 or 4*s*. 3*d*. (As. 5.)

NCAG—SM/8 No. 8. The Silk Industry of Japan with Notes on Observations in the United States of America, England, France and Italy, By C. C. Ghosh, B.A., F.E.S. (1933). Price Rs. 4 or 6*s*. 9*d*. (As. 7.)

NCAG—SM/9 No. 9. Mechanical Cultivation in India. A History of the Large-Scale Experiments carried out by Burmah-Shell Oil Storage and Distributing Company of India, Ltd., By C. P. G. Wade. Price Rs. 3-14-0 or 6*s*. 6*d*.

NCAG—SM/10 No. 10. Spotted Boll Worms in South Gujerat, by Messrs. B. P. Deshpande and N. T. Nadkarny. Price Rs. 5-14-0 or 9*s*. 6*d*.

No. 11. Investigations on the Course and Distribution of the Nerves supplying Levator anguli scapuli and Rhomboideus Muscles and the Formation of the Phrenic Nerve in the Ox, with Observations on certain Anatomical Deviations, by H. N. Chelva Ayyangar, G. M. V. C. (*In the Press*).

5. Miscellaneous Bulletins of the Imperial Council of Agricultural Research

NCAG—MB/1 No. 1. List of Publications on Indian Entomology (1930), By the Imperial Entomologist, Pusa. Price As. 14 or 1*s*. 6*d*.

NCAG—MB/2 No. 2. List of Publications on Indian Entomology (1931), By the Imperial Entomologist, Pusa. Price As. 8 or 10*d*.

NCAG—MB/3 No. 3. List of Publications on Indian Entomology (1932), By the Imperial Entomologist, Pusa. Price As. 12 or 1*s*. 3*d*.

NCAG—MB/4 No. 4. Host Plant Index of Indo-Ceylonese Coccidae, By S. Ramachandran, L.Ag. and T. V. Ramakrishna Ayyar, B.A., Ph.D., F.Z.S. Price Rs. 1-10 or 2*s*. 9*d*.

NCAG—MB/5 No. 5. List of Publications on Indian Entomology (1933). compiled by the Officiating Imperial Entomologist, Pusa. Price As. 9 or 1*s*.

NCAG—MB/6 No. 6. Bee-keeping, By C. C. Ghosh, B.A., F.E.S. (3rd Edition.) Price Rs. 1-14 or 3*s*. 3*d*.

NCAG—MB/7 No. 7. List of Publications on Indian Entomology (1934), compiled by the Officiating Imperial Entomologist and the Imperial Entomologist, Pusa. Price Rs. 1-2-0 or 2*s*.

NCAR—MB/8 No. 8. Selected Clinical Artic'es, by G. K. Sharma, G. P. V. C. and R. L. Kaura. Price As. 8 or 10*d*.

NCAR—MB/9 No. 9. Statistical Methods and their Application to Agronomy : A Bibliography, by. K. K. Guha Roy. Price Rs. 2-2 or 4*s*.

NCAR—MB/10 No. 10. Diseases of Sugarcane and Methods for their Control, by L. S. Subramaniam. Price Re. 1-14-0 or 3*s*. 3*d*.

NCAR—MB/11 No. 11. Tables of Standard Errors of Mendelian Ratios, compiled by Swarn Singh Purewal, M. Sc., Ph.D. (Cornell), and P. Krishna Rao, L. Ag. Price As. 12 or 1*s*. 3*d*.

NCAR—MB/12 No. 12. List of Publications on the Botany of Indian Crops, Part II, for the period 1928-32, by R. D. Bose. (*In the Press*).

NCAR—MB/13 No. 13. Two New Statistical Tables based upon Fisher's '*t*', by M. Vaidyanathan. Price As. 6 or 8d.

NCAR—MB/14 No. 14. List of Publications on Indian Entomology (1935). Compiled by the Imperial Entomologist, Pusa. (*In the Press*).

6. Annual Report of the Imperial Council of Agricultural Research

NCAG—AR/31 Annual Report of the Imperial Council of Agricultural Research for the years 1929-30 and 1930-31. Price As. 12 or 1*s*. 3*d*. (Anna 1.)

NCAG—AR/32 Annual Report of the Imperial Council of Agricultural Research for the year 1931-32. Price As. 6 or 8*d*. (As. 2.)

NCAG—AR/33 Annual Report of the Imperial Council of Agricultural Research for the year 1932-33. Price As. 6 or 8*d*.

NCAG—AR/34 Annual Report of the Imperial Council of Agricultural Research for the year 1933-34.

NCAG—AR/35 Annual Report of the Imperial Council of Agricultural Research for the year 1934-35.

7. Review of Agricultural Operations in India (now called Agriculture and Animal Husbandry in India).

NCAG—R.1/29 Review of Agricultural Operations in India, 1928-29. Price Rs. 3-2-0 or 5*s*. 6*d*. (As. 8.)

NCAG—R.1/31 Review of Agricultural Operations in India, 1929-31. Price Rs. 5 or 8*s*. 3*d*. (As. 10.)

NCAR—RI/31-33 Review of Agricultural Operations in India, 1931-33. Price Rs. 5-12-0 or 9*s*. 6*d*.

Agriculture and Animal Husbandry in India, Parts I and II, 1933-35. (*In the Press.*)

8. Proceedings of the Board of Agriculture and Animal Husbandry

Proceedings of the First Meeting of the Animal Husbandry Wing of the Board of Agriculture and Animal Husbandry held at New Delhi from the 20th to 23rd February 1933, with Appendices. Price Rs. 5-14-0 or 9*s*. 6*d*.

Proceedings of the First Meeting of the Crops and Soils Wing of the Board of Agriculture and Animal Husbandry in India held at Delhi from the 25th February to the 2nd March 1935, with Appendices. Price Rs. 6 or 9*s*. 6*d*.

A description of the Imperial Institute of Veterinary Research, Muktesar, and its Substation, the Imperial Veterinary Serum Institute, Izatnagar, by F. Ware, F.R.C.V.S. Price Rs. 1-4-0 or 2*s*.

The Production of Cigarette Tobacco by Flue-curing, by F. J. F. Shaw, C.I.E., D.Sc., A.R.C.S., F.L.S. and Kashi Ram. *Imp. Inst. Agri. Res. Pusa Bull.* No. 187. Reprinted (1935). Price Re. 1 or 1*s*. 9*d*.

A Handbook of Statistics for Use in Plant Breeding and Agricultural Problems, by F. J. F. Shaw, C.I.E., D.Sc., A.R.C.S., F.L.S. Price Rs. 4-6-0 or 7*s*. 3*d*.

Copies of the above publications can be had from :—

In India.—Manager of Publications, Civil Lines, Delhi.

In Europe and America.—From Public Department (Publications Branch), Office of the High Commissioner for India, India House, Aldwych, London, W.C. 2.

ERRATA

THE INDIAN JOURNAL OF AGRICULTURAL SCIENCE, VOL. VI, PART III, JUNE 1936

Page 590, line 15, *for* ' apetite ' *read* ' appetite '.
Page 598, line 16 from the bottom, *for* ' 6th July 1932 ' *read* ' 6th December 1932 '.
Page 616, line 2 from the bottom, *for* ' number ' *read* ' numbers '.
Page 634, line 10, *for* ' trocolia ' *read* ' trochela '.
Page 643, line 16, *for* ' bread ' *read* ' bred '.
Page 648, line 16 from the bottom, *for* ' arejet ' *read* ' are jet '.
Page 667, line 14 from the bottom, *for* ' soili n ' *read* ' soil in '.

GIPD—289 IC of AR—S3—19-12-36—800.